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Sraffa and ecological economics: links and future possibilities

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Titre : Sraffa et l'économie écologique : liens et possibilités

Mots clés : Sraffa, environnement, économie écologique

Résumé : Le travail de Sraffa avait pour but de critiquer le paradigme néoclassique marginaliste, en prouvant qu'une théorie économique basée sur des données objectives concernant la production et la répartition du surplus pouvait expliquer les valeurs d'échange. L'économie écologique avait également initialement pour but de proposer une critique de l'économie de l'environnement néoclassique, en mettant en avant que les décisions en matière d'environnement ne pouvaient seulement se baser sur des analyses économiques. Ma thèse étudie les relations entre ces deux écoles de pensée.

Ma conclusion principale est que l'analyse de Sraffa ne rejette pas l'évaluation monétaire de la nature parce que la nature n'a pas d'importance pour la production économique (de ce point de vue-là, la nature a au contraire une importance infinie) mais parce que le discours économique n'est pas capable d'exprimer la valeur de la nature. La théorie de Sraffa aide à définir ce que peut dire le discours économique et sur quels objets ontologiques il peut porter. Sur cette base, une économie écologique Sraffienne peut être construite et peut servir d'alternative à l'économie de l'environnement néoclassique.

Title : Sraffa and ecological economics: links and possibilities

Keywords : Sraffa, environment, ecological economics

Abstract : Sraffa's original work was intended to be a decisive criticism of the neoclassical marginalist paradigm, trying to reveal that an economic theory based on objective data about production and distribution of the surplus can explain exchange values. Ecological economics were also intended as a criticism of the neoclassical environment economics, trying to express the fact that decisions about the environment cannot be taken according to economic analyses alone. My thesis investigates how both schools interrelate.

The main point of my conclusion is that Sraffa's analysis rejects natural resources in his explanation of exchange value, not because nature is not important for the economic process (the contribution of nature is infinite in this respect), but because the economic discourse is not able to express its value. The theory of Sraffa helps to define what the economic discourse can say and what are the ontological objects of the economic analysis. From there, a Sraffian ecological economics can be built on Sraffa's basis, and it would help to construct a classical alternative to the neoclassical environmental economics.

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Sraffa and ecological economics: links and possibilities

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June 15, 2016

The natural environment has been gravely damaged by our irresponsible behaviour. The social environment has also suffered damage. Both are ultimately due to the same evil: the notion that there are no indisputable truths to guide our lives, and hence human freedom is limitless. We have forgotten that "man is not only a freedom which he creates for himself. Man does not create himself. He is spirit and will, but also nature" (Benedict XVI, Address to the Bundestag, Berlin (22 September 2011): AAS103 (2011), 664).

Encyclical letter Laudato Si', Francis, May the 24th, 2015.

Jamais la raison n'a été et ne sera capable de définir le bien et le mal ou même séparer le mal du bien, ne fût-ce qu'approximativement. Au contraire, elle les a toujours honteusement et lamentablement confondus. Quand à la science, elle n'a fourni que des solutions fondées sur la force brutale; et tout particulièrement la demi-science, le plus terrible des fléaux qui aient frappé l'humanité, pire encore que la peste, la famine, la guerre, et qui n'est apparue qu'en ce siècle. La demi-science est un despote, et l'on n'en a jamais vu de pareil jusqu'à nos jours. Un despote qui a ses prêtres et ses esclaves, devant qui l'on se prosterne avec amour et superstitieusement, devant qui tremble la science elle-même, mais qu'elle outrage honteusement.

Fedor Mikhaïlovitch Dostoïevski, Les Possédés, 1871, traduction de B. de Schlœzer, Librairie Générale Française, 1961, p. 252.

Les approches "environnementaliste" et écologiste sont donc fondamentalement différentes. La première impose de nouvelles contraintes et de nouvelles limitations au libre jeu de la rationalité économique telle qu'elle s'est développée par le capitalisme. Mais ces contraintes et ces limitations n'entament pas la tendance de fond du système à étendre la sphère de la rationalité économique et de la valorisation de quantités croissantes de capital. La société reste dominée par cette tendance de fond, au service du paradigme industrialiste. L'approche écologiste, en revanche, implique un changement de paradigme, qui peut se résumer par la devise "moins mais mieux". Elle vise à réduire la sphère dans laquelle la rationalité économique et les échanges marchands se déploient et à la mettre au service de fins sociétales et culturelles non quantifiables, au service du libre épanouissement des individus.

André Gorz. Capitalisme, Socialisme, Ecologie. Editions Galilée, 1991, p. 172-173.

Je dédicace cette thèse à mes amis doctorants de REEDS, de l'UVSQ et d'ailleurs, que j'ai croisés au cours de cette thèse et qui m'ont apporté bien plus que des sourires.

Je remercie ma famille, mes amis, qui ont créé autours de moi un environnement propice à mon épanouissement, personnel comme professionnel. Et je remercie ma femme, sa patience et sa douceur m'ont aidé à tenir, son impatience et sa colère m'ont forcé à finir !

Abstract

Sraffa's original work was intended to be a decisive criticism of the neoclassical marginalist paradigm, trying to reveal that an economic theory based on objective data about production and distribution of the surplus can explain exchange values. Ecological economics were also intended as a criticism of the neoclassical environment economics, trying to express the fact that decisions about the environment cannot be taken according to economic analyses alone. My thesis investigates how both schools interrelate. After presenting the ecological economics field (Chapter 2) and the core message of Sraffa's work (Chapter 3), I review the works within the neo-Ricardian school that deals with environmental questions in Chapter 4. Rent is touched upon by Sraffa concerning scarcity of natural resources, but I show that this revenue, in a Sraffian framework, is not necessarily linked with natural resource scarcity. Exhaustible natural resources are introduced by some neo-Ricardian authors, but almost all intend to justify the Hotelling's rule concerning royalties, which, in the perspective that I develop in this thesis, is not compatible with Sraffa's thinking. Finally several works in the neo-Ricardian school deal with waste management, pollution and renewable resources issues, which proves that a common interest can be built with the ecological economics school. In Chapter 5, I review the works within the ecological economics school that try to integrate Sraffa's thinking into their problematic. On the debate about the energy theory of value and about the value of the environment, some authors use Sraffa's model, but usually without clearly understanding the premises of it. The classical approach, as used by Sraffa, to represent the distribution of the surplus as the result of a class struggle is also exploited by some ecological economics authors in order to clarify some aspects of ecological conflicts. Finally rent and vertical integration analysis are also neo-Ricardian analytical tools that have been used in some ecological economics works. I sum up my findings and, on that basis, I draw some pathways for research that could be interesting for both schools in Chapter 6. Several directions can be built, investigating how the distribution of the surplus, the rent on environmental resources and the dynamics of exhaustion and replenishment of natural resources influence values, and how environmental impacts can be added to the existing methods of production in order to assess the environmental consequences of technical change. Finally the Sraffian paradigm can be used to shed a new light on contemporary debates such as the payment for ecosystem services and the possibility of a circular economy. The main point of my conclusion (chapter 7) is that Sraffa's analysis rejects natural resources in his explanation of exchange value, not because nature is not important for the economic process (the contribution of nature is infinite in this respect), but because the economic discourse is not able to express its value. The theory of Sraffa helps to define what the economic discourse can say and what are the ontological objects of the economic analysis. From there, a Sraffian ecological economics can be built on Sraffa's basis, and it would help to construct a classical alternative to the neoclassical environmental economics.

Contents

Chapter 1

Introduction

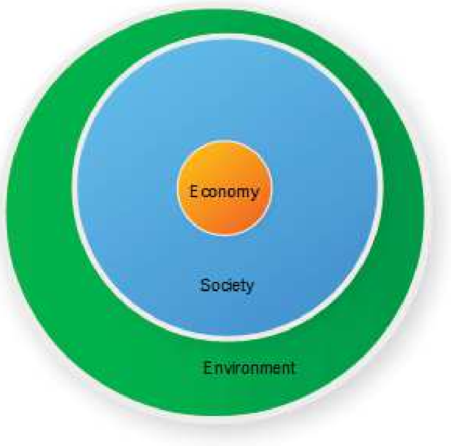
1.1 Sraffa, the neo-Ricardian school and ecological economics

My thesis deals with the connections that were made, and that could be made, between the works of Sraffa and the ecological economics field.

Piero Sraffa (1898-1983) was an Italian economist specialised on the history of economic thought. He is mainly famous for one little book, "Production of commodities by means of commodities" published in 1960. The book was intended as a criticism of the neoclassical economic theory, and presented a way of assessing the prices, the rate of profits and the wages from the exchanges of produced commodities during one period of production. Some ideas of the book were intentionally drawn from the classical economists (Quesnay, Ricardo, Torrens, Marx) and, because Sraffa was also famous for his complete re-edition of "The works and correspondence of David Ricardo" (with the help of M. H. Dobb), the researchers that attempt to investigate and develop Sraffa's premises are nowadays called the neo-Ricardians.

Ecological economics is a field of research that tries to understand the links between the economy and the environment. The field was institutionally built as an academic field of research in the 1980s, with the creation of the International Society for Ecological Economics in 1988 and the launch of the research journal "Ecological Economics" in 1989. Ecological economists start from the hypotheses that environmental resources that are available for human purpose on planet Earth are finite, that they are currently depleted by human activities, and that no economic activities can survive without them. These hypotheses are frequently summarized by Fig. 1.1 where the economic sphere is embedded into the social sphere, itself embedded into the environmental sphere.

Figure 1.1: The three spheres: the environment, the human society and the economy



In order to investigate these hypotheses, ecological economists researchers were interested to learn from different sciences and different theories inside these fields. In economics, the dominant theory is the neoclassical one. Unfortunately, this theory is not able to take into account the absolute scarcity of natural resources: from a set of finite quantities of different resources, the neoclassical theory only calculates relative scarcities. An other paradigm then seems to be needed in order to fully understand the dependency, for the economy, from environmental resources. In this context, Sraffa's theory is, from time to time, presented as an alternative paradigm that could help ecological economists to develop their vision: see for instance, in the journal Ecological Economics, the papers from Christensen (1989), Judson (1989), Patterson (1998) and Martins (2013).

The objectives of my thesis are then:

1. To present the theory of Sraffa, in the context of the theory of economic thought;

2. To critically present what the neo-Ricardian school has done concerning environmental issues;

3. To critically review the literature that tried to use Sraffa in the ecological economics field;

4. And finally to present my understanding of what could be a Sraffian ecological economics theory.

The outline of my thesis is the following:

- Chapter 2 is dedicated to the presentation of the ecological economics field, its origins and its main developments, as well as two normative positions on what should be its future as an autonomous field.

- Chapter 3 presents the core message of Sraffa's work, in relation with some important authors in the history of economics thought (Ricardo, the marginalists, Von Neumann, Leontief and the general equilibrium theory).

- In Chapter 4, I review the works within the neo-Ricardian school that deal with environmental questions. Rent is touched upon by Sraffa concerning natural resources, but, as Sraffa himself would insist, this revenue is not necessarily linked with natural resource scarcity. Exhaustible natural resources are introduced by some neo-Ricardian authors, but almost all intend to justify the Hotelling's rule concerning royalties, which, in the perspective that I develop in this thesis, is not compatible with Sraffa's thinking. Finally several works in the neo-Ricardian school deal with waste management, pollution and renewable resources issues, which proves that a common interest can be built with the ecological economics school.

- In Chapter 5, I review the works within the ecological economics school that attempt to integrate Sraffa's thinking into their problematic. On the debate about the energy theory of value and about the value of the environment, some authors use Sraffa's model, but usually without clearly understanding the premises of it. The classical approach used by Sraffa, which represents the distribution of the surplus as the result of a class struggle, is also exploited by some ecological economics authors in order clarify some aspects of ecological conflicts. Finally rent and vertical integration analysis are also neo-Ricardian analytical tools that have been used in some ecological economics works.

- Chapter 6 sums up my findings and, on that basis, draws some pathways for research that could be interesting for both schools. Several directions can be built, investigating how the distribution of the surplus, the rent on environmental resources and the dynamics of exhaustion and replenishment of natural resources influence values, and how environmental impacts can be added to the existing methods of production in order to assess the environmental consequences of technical change. Finally the Sraffian paradigm can be used to shed a new light on contemporary debates such as the payment for ecosystem services and the possibility of a circular economy.

1.2 Institutional context

This thesis was funded by the Climate-Knowledge and Innovation Community (Climate-KIC), a public-private innovation partnership created in 2010 by the European Institute of Innovation and Technology (EIT). The Climate-KIC does not necessarily share the views expressed in this thesis; responsibility for its contents rests entirely with the author.

This thesis was fulfilled under the supervision of Pr. Martin O'Connor in the International Center of Research REEDS, at the University of Versailles Saint-Quentin-en-Yvelines (UVSQ).

Chapter 2

Ecological economics

2.1 What is ecological economics

Ecological economics is a field of research attempting to gather information from different sciences (economics, ecology, but also chemistry, physics, geology, sociology, etc.) in order to understand how the economy and nature are interrelated, i.e. how the economy is affected by the environment and how the environment is affected by economic activities. Its main characteristics is then its openness to different methodologies, point of views and paradigms.

This openness sometimes appears as a difficulty when one wants to grasp what has been learned in ecological economics since its foundation: debates and controversies about concepts and visions of what should be ecological economics are never really closed. In this chapter I will first describe the origins of ecological economics in section 2.2, then I will talk about the main developments in this field in section 2.3. I will then describe the difference between this field and the field of environmental economics in section 2.4, before presenting some points of view of what should be ecological economics in section 2.5.

2.2 Origins

Røpke (2004) traces back the theoretical origins of ecological economics as a field of research to the Physiocrats, who first saw the link between land production and economic production, and to the development of thermodynamics in the middle of 19th century, which allows to describe economic processes in a physical way, as transfers of energy and matter. One of the main contributor in the development of economics as a part thermodynamic science is Georgescu-Roegen (1971), but other authors, such as chemical researchers Soddy and Ostwald, also tried to establish a link between physical and social sciences (Ostwald, 1908; Soddy, 1926). This naturalisation of economic processes expresses one of the core beliefs of ecological economics (Røpke, 2005), which is that economy and the production of economic value cannot be separated from its physical natural basis:

> “The basic observation in ecological economics is banal and difficult to disagree with: the human economy is embedded in nature, and economic processes are also always natural processes in the sense that they can be seen as biological, physical and chemical processes and transformations” (Røpke, 2004).

Ecology first appeared as a concept in 1866 (Haeckel, 1866), and became a science in the late XIX$^{\text{th}}$century. It concerns the study of the interactions between species, and the study of specific systems of species (the term “ecosystem” first appears in Tansley, 1935). Some ecologists analyze ecosystems by looking at their exchanges of energy and matter inside the ecosystem, and between the ecosystem and its environment (Odum, 1953). The development of system theory and cybernetics in the 1950s influenced the development of this part of ecological sciences, leading to analyzes of the interactions inside and between large ecosystems, and between ecosystems and human society (Odum, 1971), and to the development of ecological anthropology (Rappaport, 1968).

Social changes in the awareness of human impact on the environment then helped the construction of ecological economics as a field of research which could answer a social need. Rachel Carson’s book (1962) on the impact of pesticides was one of the first spark, and in the 1960s almost all western countries started to develop environmental regulations on hazardous wastes and pollutants, following social protests on this questions (Commoner, 1966). Furthermore, discussions on the increase of world population and on the sufficiency of food supply were raised (Ehrlich, 1968), related with the question of the development of poor countries, and more widely with the question of the management of natural resources at the global level (Meadows et al., 1972). All these concerns were discussed during the United Nations Conference on the Human Environment in Stockholm in 1972, which “demonstrated that the challenges in relation to the environment, population growth and resources were now widely acknowledged” (Røpke, 2004). And finally the oil crisis in 1973 was seen by many as a confirmation that new economic models explicitly taking account on the environment should be developed.

Environmental economics, focusing on the management of natural resources (renewable and non renewable), the management of negative externalities (pollution) and on the utility created by the environment (recreational, cultural, aesthetic and religious amenities), were then developed as a specific branch of the current dominant paradigm in economics, the neoclassical theory. However, some researchers (Boulding, 1966; Daly, 1968; Ayres and Kneese, 1969; Georgescu-Roegen, 1971) already called, through their works, for a different paradigm, where economy is described as embedded into the natural sphere, dependent on limited natural resources, and which cannot escape from producing wastes, i.e. to have a more holistic and physical point of view of the economic production process. But the apparition of ecological economics as an institutional field came later:

> "In the beginning of the 1970s, the basic ideas that later became foundational for ecological economics were given modern formulations, but it took more than 15 years before ecological economics actually took shape as a field of research" (Røpke, 2004).

This institutionalisation was made possible first through the diffusion of initial ideas by the help of more accessible papers and books (Daly, 1977; Georgescu-Roegen, 1979); Ignacy Sachs (1974) and René Passet (1979) also helped to broadcast the ideas in the French scientific world. Simultaneously, a wide discussion started on the management of energy and the relation between energy consumption and value creation (Pimentel et al., 1973; Costanza, 1980; Cleveland et al., 1984) and the development of Prigogine's thermodynamics (Prigogine, 1972) helps to keep high the interest on general system theory and on transdisciplinarity, as ecosystems and human society could be described as a far-from-equilibrium self-organizing dissipative structure (Perrings, 1987). The notion of "resilience" of ecosystems also was invented in that time, in relation to the rise of chaos theory (Holling, 1973), which was used to point out that human action could have very unpredictable results on the environment.

The intellectual, social and institutional framework was then ready for the appearance of this new field: this was made effective through the connections and meetings between several influential researchers, such as Herman Daly, AnnMari Jansson, Robert Costanza and Joan Martinez-Alier (Røpke, 2004), and through symposiums organized in Stockholm in 1982, and in Barcelona in 1987. After these meetings the International Society of Ecological Economics (ISEE) was created in 1988 with Costanza as the first president and the journal "Ecological Economics" was launched in 1989 with Costanza as the chief editor and Daly, A.M. Jansson and Pearce the initial associate editors. In Europe, the European Society for Ecological Economics (ESEE) was created in 1996, during the International Conference Ecology Society Economy hosted by the Université de Versailles Saint-Quentin-en-Yvelines (UVSQ) in France. Sylvie Faucheux was the first president, and with Martin O'Connor they help to diffuse the ecological economics ideas in the french academic world, with the creation of the research center C3ED (Centre d'économie et d'éthique pour l'environnement et le développement) in the UVSQ.[1]

[1]The C3ED disappeared in 2009 and was divided into two research centers, REEDS (Centre de Recherches en économie-écologique, éco-innovation et ingénierie du Développement Soutenable) and CEMOTEV (Centre d'études sur la mondialisation, les conflits, les territoires et les vulnérabilités).

2.3 Main developments

The beginning of ecological economics was the result of the meeting of two research groups: ecologists interested in thermodynamics, assessing the flows of energy and matter which are exchanged in an ecosystem and the inclusion into this ecosystem of human processes; and economists also interested in thermodynamics, assessing the flows of energy and matter needed by the economic system. This intersection leads to the core position for ecological economics that nature and economy are closely interrelated, that economy processes could be seen (but not only) as natural object, and that, in this view, human economy is embedded into nature (Røpke, 2005). Thus environmental problems should then be taken seriously: if the scale of the economy becomes too big, the support of human life could be destroyed (Daly, 1977; Costanza, 1989). A second core position is that interdisciplinary works are needed in order to understand and solve these environmental problems (Røpke, 2004).

Instead of core positions, Røpke (2005) refers to "core beliefs" which act as "a shared framework of understanding", indicating "directions for research" for ecological economists researchers: apart from the first two already addressed, she also lists pluralism, basic ignorance about the results of the interactions between human society and its environment, system thinking, a focus on equity and distribution, the idea that nature has value in itself and that the economy is embedded in a broader socio-cultural system. Other unifying themes are, for Merino-Saum and Roman (2012), the interest for time and for an efficient allocation of resources, the explicit account of future generations, the notion that there exists incommensurability of values when dealing with human-nature relations, that uncertainty and path-dependency prevail in human-nature relations and the idea that natural capital cannot be totally substituted by other forms of capital.

The pluralism and the call for transdisciplinarity works has been a success. Today authors writing in the journal mainly comes from standard neoclassical economy, institutional economics, post-Keynesian economics, ecology, political ecology, sociology, anthropology, environmental ethics and environmental history (Merino-Saum and Roman, 2012).

The scale issue leads to the development of Mass Flow Analysis (MFA), to the analyses of social metabolism (Fischer-Kowalski and Hüttler, 1999) and to the development of indicators such as rucksacks, Material Input Per unit of Service (MIPS), ecological footprints (Wackernagel and Rees, 1996), water footprints and Human Appropriation of Natural Primary Production (HANPP, Vitousek et al., 1997). Energy studies started long before the institutionalisation of ecological economics, but were continued, particularly inside the debate about the relevance of an energy value theory (Giampietro and Mayumi, 2000). Questions about the relation between income and environmental appropriation and pollution were then raised, leading to researches on environmental justice (Andersson and Lindroth, 2001; Schor, 2005) and environmental conflicts (Martinez-Alier, 2002).

Related to environmental conflicts, the issue about the value of nature (why should we protect nature) and the acceptance of both facts that some values cannot be measured by the same indicator (incommensurability of values, Martinez-Alier et al., 1998) and that valuation is a social and political process leads to the development of new decision support tools in order to inform and to guide political decisions which could affect the environment. Multicriteria analysis were developed in this respect (Munda et al., 1994; Munda, 2004) and participative and deliberative approaches were also elaborated in order to take decisions on the basis of different value systems, to overcome social choice theory impasses (Arrow, 1950) and situations of uncertainty (Funtowicz and Ravetz, 1994b), in the context of institutional analysis, territorial prospective, risk governance, political ecology, etc. (Merino-Saum and Roman, 2012). The debate around the value of nature is still very active nowadays, especially with the birth of the notion of ecosystem services (MEA, 2005): this concept is widely used in ecological economics but can lead to the monetarisation of nature (e.g. in TEEB, 2010). It is then criticized as an anthropocentric and too much simplified representation of nature (Norgaard, 2010).

The notion of our insufficient knowledge about consequences of human action on the environment leads to the development of research on the concept of resilience and on the precautionary principle and on the management of ecosystems (Levin et al., 1998; Folke, 1999), attempting to answer the question: how to ensure that ecosystems and human societies can adapt to environmental crises and changes? This also raised research on the debated concept of coevolution of nature and society (Norgaard, 1988; Gowdy, 1994). Finally the concept of degrowth (Meadows et al., 1972; Georgescu-Roegen, 1995) shows recently a raising interest in the field of ecological economics (van den Bergh, 2011), following the call from Peter Victor (2008) to develop ecological macroeconomics.

2.4 Difference between environmental economics and ecological economics

Environmental economics is building on the neoclassical theory in order to take into account environmental problems, which are mainly the destruction of environmental amenities (for instance due to waste disposal) and the extinction of natural resources. On the first problem, welfare economics (the branch of neoclassical economics dealing with this kind of problem) assume that environmental consequences of human actions can be translated into utility, and thus in prices (the goal is to "internalize externalities", Pigou, 1920; Coase, 1960). On the second problem, neoclassical resources economists develops models that works on intermediate time-span time ("They are intended to help us answer questions like, for the intermediate run - for the next 50-60 years, is it possible that growth can be sustained?", Stiglitz, 1997), based on optimistic assumptions about substitutability between natural and manufactured capital (the possibility of back-stop technologies,[2] e.g. see Solow, 1974, 1997), and on the belief that, if markets are "working well" (i.e. if there is free competition), the scarcity of resources will be reflected on prices.

The main problem of these constructions, for an ecological economics point of view, is that they rely on a partial and narrow view of the interactions between human society and its environment. The utility point of view, expressed in the willingness-to-pay or willingness-to-accept studies that are developed in welfare economics, cannot capture all interactions and services that ecosystems furnish, and all values that can be attached to them (for most ecological economists, values can be incommensurable). And the intermediate time span models are necessarily blind to the dependence of economic production on absolutely scarce natural resources:

> "the message that externalities are pervasive and potentially threatening for the life support of the human economy was nearly invisible in environmental economics ... Mainstream economists took on the role of explaining that there are no limits to economic growth - especially after the publication of The Limits to Growth in 1972 (Meadows et al., 1972). The main arguments were introduced in Barnett and Morse's classic from 1963 (Barnett and Morse, 1963): the price system and technical change will do the job" (Røpke, 2004).

This debate between the good scale to consider or the right time span is sometimes referred to as the debate between the Weak Sustainability paradigm (sectorial or regional analysis, intermediate time span) and the Strong Sustainability paradigm (global scale, long-term time span).

[2]"Pour certains économistes, les forces du marché conduisent à l'apparition de nouvelles technologies permettant toujours de pallier la raréfaction des ressources, ce qui implique que ces dernières soient virtuellement illimitées. L'exploitation des sables bitumineux ou la production d'éthanol seraient des backstop technologies permettant de remplacer le pétrole conventionnel" (Merino-Saum and Roman, 2012).

Ecological economics were then partly built in opposition to environmental economics:

> "some of the most active economists behind ecological economics, such as Daly and Martinez-Alier, were at odds with mainstream economics. Daly's motive for engaging in cooperation with ecologists was related to the development of mainstream environmental and resource economics, where the biophysical perspective virtually disappeared for a long period. He would really have liked to change the discipline from inside rather than creating a new field, but he came to the conclusion that this was not realistic" (Røpke, 2004).

Nevertheless, pluralism of theories was one of the core belief of ecological economics since their creation (Costanza, 1989) and papers based on neoclassical assumptions are still published in the Journal of Ecological Economics.

Besides this call from the early authors of ecological economics to an economic approach focusing on the insights from ecology and the natural sciences, which leads to the creation of the ecological economics field, a movement inside economics was already calling from different approach than the neoclassical one. Following the research program of Kapp (1970), they developed socio-economic and institutional approaches (not necessarily related to environmental questions) and were attracted by the ecological economics field as it was a new place where they could express their ideas (Söderbaum, 1992). The last of the core belief expressed by Røpke (2005) is in relation with the core principle of these socio-economic approaches: economy is embedded into a set of social processes and cultural meanings and values. This view of economy is for instance attempting to highlight that there are political aspects in all valuation procedures, especially for the valuation of ecosystem services. Thus socio-economists are more akin to use participatory and multicriteria methods for valuation of these services. Van den Bergh (2001) summarises in Table 2.1 the differences between both approaches:

Table 2.1: Differences in approaches between ecological economics and environment economics (from van den Bergh, 2001)

Ecological economics	Traditional environmental and resource economics
1. Optimal scale	1. Optimal allocation and externalities
2. Priority to sustainability	2. Priority to efficiency
3. Needs fulfilled and equitable distribution	3. Optimal welfare or Pareto efficiency
4. Sustainable development, globally and North/South	4. Sustainable growth in abstract models
5. Growth pessimism and difficult choices	5. Growth optimism and "win-win" options
6. Unpredictable co-evolution	6. Deterministic optimisation of intertemporal welfare
7. Long-term focus	7. Short- to medium-term focus
8. Complete, integrative and descriptive	8. Partial, monodisciplinary and analytical
9. Concrete and specific	9. Abstract and general
10. Physical and biological indicators	10. Monetary indicators
11. Systems analysis	11. External costs and economic valuation
12. Multidimensional evaluation	12. Cost-benefit analysis
13. Integrated models with cause–effect relationships	13. Applied general equilibrium models with external costs
14. Bounded individual rationality and uncertainty	14. Maximisation of utility or profit
15. Local communities	15. Global market and isolated individuals
16. Environmental ethics	16. Utilitarianism and functionalism

The differences between both approaches is especially perceptible in the debate around the economic valuation of nature and nature services:

> "It is noteworthy that 'Most ecologists would argue that ecosystem services and support are essential for society irrespective of whether or not they are perceived as important by humans' (Folke, 1999, p. 907). However, this has not deterred researchers from trying to assess the economic value of ecosystem services based on contingent valuation. The awareness of uncertainty implies that adherents of this programme try to take, for example threshold effects into account, although this can be difficult to combine with traditional neoclassical methods. Most studies have been assessments in monetary terms, but some have supplemented with values based on energy analysis - another form of value monism. Arguing for the relevance of this approach, the adherents emphasize 'All decisions concerning the allocation of environmental resources imply the valuation of those resources...We can choose to make these valuations explicit or not' (Costanza et al., 1997, Introduction Section 5). This argument seems to imply that the only possible form of valuation must be based on value monism and has to be dealt with by scientific experts, and therefore, we must try to make such assessments as good as possible. This way of thinking is at odds with the socio-economic perspective of incommensurability, which emphasizes the basically political character of environmental decision-making, the importance of social conflicts and the need for developing social institutions to handle these conflicts" (Røpke, 2005).

This quotation helps us to understand why pluralism of theories inside ecological economics is sometimes difficult to maintain. The neoclassical theory is seen by some ecological economists as part of the environmental problem, because this theory is based on premises which leads to a certain vision of the human society (pro-individualist, pro-market). This vision and the result from the theory are then used to inform public decision-makers:

> "environmental economists argue that the environmental standard-setting by scientists and policy makers should be based purely on the 'economic criterion' namely, the optimal level of pollution determined by the marginal costs and marginal benefits of controlling pollution" (Venkatachalam, 2007).

Some researchers inside the ecological economics field then think that not only they should develop alternative theories, but furthermore they should fight against the neoclassical paradigm:

> "The present dominance of the neoclassical paradigm contributes to the legitimization of policies that are seriously detrimental to the poor and destroy ecosystems and life conditions for other species to

serve the short-term interests of the richest fifth of the world's population. Therefore, it is an urgent task for academics to undermine and uproot the basic understanding that allows such legitimization, and it is decisive to provide alternative understandings for new generations, not least in relation to the education of economists (sharing to a large extent the programme of the movement for post-autistic economics, see www.paecon.net)" (Røpke, 2005).

2.5 The current visions/what should be ecological economics

The question of what should become ecological economics forces one to define his normative positions about what is the role and the capacity of science (and more specifically of the methods developed in the ecological economics field) and what are the goals that he thinks the field should pursue. The role and capacity of science is related to epistemic questions, such as how can we prove something wrong, themselves related to ontological positions about what exists (what are the basic objects on which we could apply our scientific methodology). The goals that we should pursue relates to ideological ends. I mainly refers in this section on two recent papers which, in my opinion, expresses the two different positions about these questions that are nowadays dominant in the ecological fields: Baumgärtner and Quaas (2010) and Spash (2012).

Ecological economics is torn in half between pragmatism, expressed by its American branch (an example of this pragmatic approach is the development, inside the ecological economics field, of the notion of ecosystem services and the participation into the The Economics of Ecosystems and Biodiversity report, TEEB, 2010), and social ecological economics, lead by the European Society for Ecological Economics and more particularly by Clive Spash (Merino-Saum and Roman, 2012). The current trend is actually in favor of the pragmatic side and the discourse inside the ecological economics field is not very distinct from environmental economics discourse anymore, which is a discourse based on neoclassical premises (see the study on that point from Plumecocq, 2014).

The closing gap between neoclassical economics and ecological economics may be in line with the desire for methodological pluralism, explicitly expressed in the beginning of the field (Costanza, 1989). This integration seems to be favoured for instance by Baumgärtner and Quaas (2010). They develop the wide concept of "sustainability economics", aiming to encompass inside both ecological economics and neoclassical approaches. The question that sustainability economics should answer is:

> "How can we understand and manage the relationships between humans and nature over the long run so that scarce natural resources, goods and services, as well as their human-made substitutes and complements, are being used efficiently for the satisfaction of human needs and wants and in a just manner?" (Baumgärtner and Quaas, 2010).

The epistemic positions and the ontological objects are not specified and thus methodological options are left open (such as the choice between "weak" or "strong" sustainability paradigm).[3] However normative positions about justice

[3] This non-choice has been criticized by Spash on the ground that accepting different epistemologies leads to "simultaneously holding two (or more?) contradictory ways of understand the meaning of knowledge" (Spash, 2012).

and the goal of economics are asserted.

The notion of justice as a normative goal that should be pursued between humans (inter and intra-generational justice) and humans and nature is defended by Baumgärtner and Quaas. This entails that nature should be protected for its own sake (and not in a utilitarian sense). Adding with this a focus on time, Baumgärtner and Quaas appear to be very close from the normative positions defended for instance by Røpke (2005) and Faber: "Ecological Economics is an attempt to consider economics and nature according to the prerequisite that besides the dignity of humans an independent 'dignity of nature' has to be respected" (Faber, 2008). However the normative goal of economic science is disputable, and Baumgärtner and Quaas recognize it: the focus on individual wants refers to liberal and utilitarian roots that can be simultaneously defended (Hayek, 1948) and criticized (Sen, 1999) on ethical grounds. And furthermore they linked this goal with the neoclassical methodology, by defining economics as "the science which studies human behaviour between ends and scarce means, which have alternative uses" (Robbins, 1932). This definition of economics is actually rejected by Faber (2008) and Martins (2013), for instance. Thus the enterprise of Baumgärtner and Quaas appears to be a failure, as their vision of economics does not encompass all the different position that exist in ecological economics.

A more radical view is the one developed by Spash (2012): as the integration between neoclassical economics and ecological economics is doomed to epistemic contradictions and failure to encompass all the ecological economics tradition, a choice has to be made between methodological pluralism and epistemic consistency. According to him, the neoclassical paradigm has to be rejected:

> "ecological economics can either develop a more rigorous approach and establish a theoretical structure or become increasingly eclectic, unfocused and irrelevant. Ecological economics as a conservative movement is an unnecessary waste of time, merely shadowing environmental and resource economics. Ecological economics as a radical movement is required today, more than ever, in order to criticise and change the social organisations and institutions that spread false beliefs about economic, social and environmental reality" (Spash, 2012).

His argument to reject the neoclassical theory is related to his vision for the field, i.e. his choices considering objects to study, and which epistemology and ideology ecological economists should follow. Following the critical realism approach, he believes that a real world exists, but that claims concerning this real world cannot be proven right or false. He is thus arguing against the neoclassical positivism (Friedman, 1953), which asserts that definite claims can be asserted on real facts, and thus that science can and should be unified. In addition, he is rejecting social constructivism, that asserts that objective real world does not exist (it is always a social construction), and logical empiricism, which asserts that a theory is right as long as its intern coherence is logical and that it is not falsified by any observable facts. For him, object of sciences can be defined, and one hierarchy between sciences can be set (e.g., the laws of physics applies to biology, the laws of biology applies to anthropology, etc.).

Spash's new epistemology for ecological economics is not opposed to other heterodox stream of thought in economics, and he calls for a rapprochement with post-Keynesian and institutional economics. In this epistemology, economics is a social science, which means that economic facts includes ideas. Thus discoursing on the reality of economic facts is discoursing on the relevance of ideas, and on the institutions that defend these ideas:

> "False beliefs may be spread in order to preserve the institution and its power. Thus, the rhetoric of the liberating character of 'free-markets' and benefits of material growth may be used by corporations and governments extracting resources, dislocating indigenous populations and creating environmental destruction. In such cases to propound the truth is not just to criticise, but to undermine the institution" (Spash, 2012).

Chapter 3

Neo-Ricardian Economics

Sraffa's work is intended as a "Prelude to a critique of economic theory", as the subtitle of his book indicates (Sraffa, 1960). By economic theory, Sraffa means the marginal theory (or the neoclassical theory, we will not distinguish between both terms here):

> "It is ... a peculiar feature of the set of propositions now published that, although they do not enter into any discussion of the marginal theory of value and distribution, they have nevertheless been designed to serve as the basis for a critique of that theory" (Sraffa, 1960, Preface).

His proposal does not have any relation with the marginal theory because it is based on the classical theory developed by Smith and Ricardo:

> "the investigation is concerned exclusively with such properties of an economic system as do not depend on changes in the scale of production or in the proportion of 'factors'. This standpoint, which is that of the old classical economists from Adam Smith to Ricardo, has been submerged and forgotten since the advent of the 'marginal' method" (Sraffa, 1960, Preface).

This is why we begin this chapter by introducing Ricardo's theory and the advent of (and some problems related to) the marginal theory in section 3.1.1. We will then present Sraffa's model in section 3.2. Sraffa only wrote one book about his theory, and hardly made any comments on the debate following its publication. The interpretation of his work goes in two directions that will be presented in section 3.3. We will then see how his model differs from Leontief's, Von Neumann's and the general equilibrium model in section 3.4.

3.1 Ricardo, marginal (or neoclassical) theory, and the Cambridge controversy

3.1.1 The model of Ricardo

David Ricardo, in his main book (Ricardo, 1817), assumes that national revenue is divided into three flows, wages, profits and rents, which are the streams of revenue earned by the three classes of the society: workers, capitalists and rentiers. According to him, the analysis of the variations in this distribution is the central element of Political Economy: "to determine the laws which regulate this distribution, is the principal problem in Political Economy" (Ricardo, 1817).

The dynamics of Ricardo's model is the following one: profits earned by capitalists are entirely re-invested. The demand for human labor then increases: wages thus also increase. Population will then rise as well (as conceptualised by Malthus in his theory on subsistence wage, see Malthus, 1817). Agriculture, which is not subject to technical progress, is forced to cultivate less productive lands, or to intensify the production in the fertile lands. As a result decreasing returns to scale in agriculture will occur: profits will thus diminish, until investments stop. Wages will then also get lower, and the population will decrease.

3.1.1.1 One sector model

We can represent Ricardo's system of production in the following way: we assume that economy is producing only one good, corn, using both capital and labor (I am referring here to the presentation of Pasinetti, 1975, p. 9). The only required capital is the wage which is given to the workers before the production process. The system is represented in this way:

$$X = f(N) \tag{3.1}$$

With the three conditions that $f(0) \geq 0$, $f'(1) > \bar{x}$ and $f''(N) < 0$.

$$R = f(N) - Nf'(N) \tag{3.2}$$

$$W = Nx \tag{3.3}$$

$$K = W \tag{3.4}$$

$$P = X - R - W \tag{3.5}$$

With X the produced quantity of corn, N the number of workers, R the total of the rents, W the wages, K the circulating capital, P the profits and x the uniform wage per worker. Equation 3.1 states that production of corn depends on labor and circulating capital (because the latter is used to remunerate labor). The first condition guarantees that there is no negative production. The second that the marginal product (of labor and capital) must be higher than the subsistence wage. This means that if we add one worker, the surplus of production compared to the previous situation must be enough to pay the additional worker so that he can survive. The third condition states that returns to scale are decreasing.[1] Equation 3.2 shows that the total of rents equals to the difference between corn production and the joint marginal product of labor and capital multiplied by the number of workers. Thus factors of production (labor cost and capital cost) are remunerated depending on the productivity of the last added worker; the rests of the production is given to the rentiers.[2]

We have then five equations and seven unknowns. Ricardo assumes that circulating capital is an exogenous data, and that the wage per worker always equals to the subsistence wage, which is also an exogenous data:

$$K = \bar{K} \tag{3.6}$$

$$x = \bar{x} \tag{3.7}$$

We can note that with equations 3.3, 3.4, 3.6 and 3.7 the number of workers is an endogenous data, i.e. it is calculated when the system is at the state of *natural equilibrium* (which does not mean a full-employment equilibrium). Wages are considered as means of production, and the surplus is divided between profits and rents. If we suppose that capitalists reinvest their profits increasing the fund of wages, this surplus will decrease as soon as production increases, as returns to scale are decreasing. Profits will tend to disappear, until the point where productivity of the last added worker will equal the subsistence wage: then profits will entirely disappear, and it will not be possible to advance the wage for one supplementary worker anymore. The system of production will be in a *stationary state.*

3.1.1.2 Pluri-sectoral model

Others industries can be added to this very simple system: however the way the rent is taken into account does not change, it still represents the payment for a difference of productivity between the different methods of production, here represented by different proportions of the factors needed to produce a given good. The payment of the rent is made on the surplus of the corn sector, and it is measured in physical quantities: thus there is no problem of rent valuation. If we define sector 2 as a constant return to scale industry producing gold, we can represent Ricardo's model with two sectors through the following 15 equations (Pasinetti, 1975, p. 13):

$$X_1 = f(N_1) \tag{3.8}$$

[1] Only intensive rent is considered here, for the sake of simplicity.

[2] Thus if there were only constant returns to scale, there would be no rent.

With the three conditions $f(0) \geq 0$, $f'(1) > \bar{x}$ and $f''(N_1) < 0$.

$$R = f(N_1) - N_1 f'(N_1) \tag{3.9}$$

$$W = Nx \tag{3.10}$$

$$K = W \tag{3.11}$$

$$P_1 = X_1 - R - N_1 x \tag{3.12}$$

$$K = \bar{K} \tag{3.13}$$

$$x = \bar{x} \tag{3.14}$$

$$X_2 = \alpha N_2 \tag{3.15}$$

Withα the quantity of gold produced per worker.

$$N = N_1 + N_2 \tag{3.16}$$

$$w = x p_1 \tag{3.17}$$

With w the wage per worker, uniform in both sectors, which equals to the price of the quantity of corn which allows the subsistence of the worker.

$$\Pi = \frac{P_1 p_1 + P_2 p_2}{K p_1} \tag{3.18}$$

With Π the uniform rate of profit in both sectors.

$$P_2 p_2 = X_2 p_2 - N_2 w \tag{3.19}$$

$$\frac{p_2 X_2}{N_2} = \frac{p_1 (X_1 - R)}{N_1} \tag{3.20}$$

This last equation states that in equilibrium, the value produced by one worker is the same in every industry, after the payment of the rents. We can note that three hypotheses stand behind this equation: uniformity of the wage per worker, uniformity of the rate of profit (both because of free competition) and uniformity of the ratio capital/labor (expressed by equations 3.10, 3.11 and 3.13, the only capital being wages paid before the production process).

If the value of the quantity of gold produced per worker is chosen as the numeraire, and if we assume that rentiers spend all the rent to buy gold, the system is determined:

$$\alpha p_2 = 1 \tag{3.21}$$

$$p_2 X_2 = p_1 R \tag{3.22}$$

Prices are then independently determined from the distribution of the surplus between profits, wages and rents:

$$p_1 = \frac{1}{f'(N_1)} \tag{3.23}$$

$$p_2 = \frac{1}{\alpha} \tag{3.24}$$

We have thus a labor theory of value. The distribution variables are linked between them by the following equations:

$$w = \frac{\bar{x}}{f'(N_1)} \tag{3.25}$$

$$\Pi = \frac{f'(N_1)}{\bar{x}} - 1 \tag{3.26}$$

It is to be noted that these variables only depend on the conditions of production in the corn sector, i.e. in the sector producing the subsistence goods: a tax or a technical change in this industry will then have consequences on all industries, through changes in the wage per worker and the rate of profit, both of which are uniform in all industries. In return, a tax in the sector of luxury goods, here the gold industry, will only impact on the price of luxury goods.

Ricardo therefore built a theory of value and a theory of distribution. However, the last of his three hypotheses, concerning the uniformity of the ratio of capital upon labor, is not realistic. If it is removed, prices become dependent on the distribution of the revenue. It is Sraffa (1960) who first found a measure of value which does not vary in relation to distribution: the standard commodity, enabling to separate clearly the questions of value of commodities and distribution of revenues. However, before that, the economic theory, with the development of the marginalist thinking, will attempt to overcome the labor theory of value by expanding the treatment of the rent to all factors of production.

3.1.2 The marginalist theory

3.1.2.1 The "law of decreasing returns" and the absence of technical progress

The classical theory of rent is in fact the starting point of the marginalist school, which has expanded it to all factors of production, besides land. This theory is originally based on five articles written in February 1815 by Malthus (1815a; 1815b), West (1815), Torrens (1815) and Ricardo (1815). These five articles make references to the "law of decreasing returns" which is supposed to apply to agriculture in case of absence of technical progress. Two years later, in 1817, Ricardo publishes his Principles of Political Economy and Taxation (Ricardo, 1817), where his theory of rent is developed more clearly (cf. 3.1.1). Smith (1776) earlier talked about rent as a sort of "monopoly price". After the publication of the five articles and Ricardo's book, rent appears as a consequence of the scarcity of fertile lands (the demand is too high regarding the supply at the normal rate of profit, and thus intensive rent appears as a result of the intensification of the production in the fertile lands, with decreasing returns to scale) and of the non-uniform quality of natural resources in general (the difference in terms of productivity between the different qualities of the same natural resource explains the extensive rent).

Pasinetti (1999) shows that this theory has been anticipated by James Anderson in a work published in 1777 (Anderson, 1777), at least for the part concerning the extensive rent.[3] However, Anderson was an opponent of the "law of decreasing returns", since he believed that technical progress could counterbalance the law (so that the lands would become more fertile). But this law was considered as a empirical fact for agriculture in those five articles because of temporary events that occurred in Great-Britain during the 1810s (a rise in the population level, Napoleon wars and difficulties for importing corn). Furthermore this law favored the theory of Malthus (1817) about population dynamics, and thus he promoted it as a natural law, proved by real facts (which were actually short-term facts).

While all these authors decided to support this law, they agreed that the law did not apply to the other economic sectors. And Ricardo makes clear in his article that he is assuming the hypothesis that there is no technical progress in agriculture, or at least not enough to counter-balance the demand increase. With this starting hypothesis, he can easily demonstrate that less fertile lands will be cultivated, that rents will increase and that the rate of profit will decrease until the stationary state is reached, where (minimal) wages and (maximal) rents will be the only incomes. However, despite these precautions, the "law of decreasing returns", a theoretical hypothesis not verified by empirical facts, was largely accepted by the economists and, in particular, was adopted for the agricultural sector by Mill (1821) and Stuart Mill (1848a).

Marx, on the other hand, was against it, as he was clear-headed on the fact that this law emerged from the distinctive economic situation of Great Britain in the beginning of the XIX$^{\text{th}}$century. However he makes references to a "law of the fall of profits", created by the perpetual contradiction between capitalistic accumulation and the simultaneous perpetual destruction of the conditions of this accumulation. He acknowledges that technical progress occurs in the industries, in order to accumulate more capital; but he was pessimistic concerning the possibility of a perpetual increase of this progress.

[3] Marx (1863) also comments on Anderson's theory of rent.

3.1.2.2 The marginalists expand the range of these two hypotheses to the whole economy

The marginalist theory starts from the marginalist approach of prices jointly developed by Jevons (1865), Menger (1871) and Walras (1874) and establishes a theory of production in the 1890's, especially through the works of Wicksteed (1894) and Wicksell (1934). The marginalist theorists adopt the theory of the differential rent, where the marginal land is used to fix the prices, and expand it to all factors of production. However, they do this by adjusting the theory of rent and the characterisation of the factors of production.

As regards the theory of rent, they only keep intensive rent (with a fix quantity of homogeneous land, the extensive rent is discarded, cf. Böhm-Bawerk, 1889) and the famous "law of decreasing returns". Furthermore they assume that the theory applies to all factors of production (land, capital and labor); so all factors of production are assumed to be scarce and likely to generate intensive rents (cf. Wicksell, 1934). The last factor used in production is the least productive, and thus it is used to fix the price of the factor.

The analysis of technical progress thus disappears from the scope of economic analysis. While there are two solutions to avoid the Ricardian stationary state: international exchanges and technical progress, the marginalists abandoned the study of the second solution by generalizing the intensive rent treatment to all factors of production: "by a dramatic under-estimation of historical events, they made the wrong choice" (Pasinetti, 1999). And the mistake was later worsened, when economics became only interested in the efficient allocation of a given set of factors of production: "from a science that inquires into the nature and causes of the wealth of nations, as it was intended by Adam Smith, they made it [...] a science that deals with the use of scarce means to achieve given ends" (Pasinetti, 1999).

The marginal theory is an approach focused on the optimal distribution and consumption of a given fund of resources, in terms of utility.[4] A theory of exchanges is developed, based on three principles:

1. Utility functions are known, continuous and differentiable, and we can thus define the concept of *marginal utility*;
2. These functions are convex, which implies that there will be *substitution* between the different commodities when their prices will vary;
3. Prices are *scarcity indexes* and represent, in equilibrium, the optimal coefficients of allocation of the existing resources.

Symmetrical principles are developed for the production process:

1. Production functions are known, continuous and differentiable, so we can define the concept of *marginal productivity*;

[4] My presentation of the marginalist theory owes a lot to Pasinetti (1975, p. 24).

2. These functions are convex, so there will be *substitution* between the different factors of production when their prices will vary;
3. The rate of profit, the wages and the rents are lumped together with prices, i.e. are considered as scarcity indexes, and represents the *optimal distributors* of capital, labor and land resources.

A change in production can appear in two ways in the marginalist theory: a change in the scale of production, and a change in the proportion between factors. In the second case, the proportion between factors inversely follows the proportion between their prices (the more expensive a factor becomes, the less it is used): this assertion is not supported by empirical facts, but is needed if the functions of production have to be convex. For example, with two factors of production, labor and capital, if the proportion of capital increases, the production is supposed to increase, while the rate of profit is supposed to decrease. However, this change of proportion is not a change in the technology: factors of production are considered to be substitutable inside a constant technology (only the proportions or the scale are changing, Clark, 1899).

3.1.2.3 WICKSELL's model

Wicksell (1934) particularly developed the marginalist theory of production, first through a simple model where the only process of production just needed land and labor as inputs. The proportion of these two factors can vary, and thus the process can be represented in this way (Samuelson, 1964):

$$Y = \varphi(L, T) \tag{3.27}$$

With Y the physical net product, L the quantity of labor and T the quantity of land. We can connect these physical quantities and the values by assuming the following accounting equality:

$$Yp = wL + rT \tag{3.28}$$

With p the unit price of the commodity produced, w the wage and r the rent, both measured in value (because they are equivalent to prices). The marginalist theory says that if the process of production is conducted by the land-owners, the maximum wage will be equal to the partial derivative $\delta Y/\delta L$, and that if the process of production is conducted by the workers, the maximum rent would be equal to $\delta Y/\delta T$. If we assume that function $\varphi(L, T)$ is homogeneous and of degree 1 (i.e. a linear function), we can then observe that wages and rents can be equal, at the same time, to the marginal productivity of their corresponding factor of production, L and T:

$$Yp = \frac{\delta\varphi}{\delta L}L + \frac{\delta\varphi}{\delta T}T \tag{3.29}$$

If, furthermore, the convexity of the function of production is assumed, then we get constant returns to scale, and decreasing returns concerning variations of the proportion between the factors (Pasinetti, 2000). Thus, if these assumptions are true, free competition and profit optimization will lead, through exchanges, to the fairest distribution of the production.[5]

3.1.3 The Cambridge controversy

3.1.3.1 Neoclassical aggregated function of production

We can add other factors of production to Wicksell's model, provided that they are measurable in physical quantities. This is why the factor *capital* leads to serious theoretical problems (even if some neoclassical authors do not realise it, for instance Meade, 1962). The rate of profit is not a price (neither a scarcity index) given to a physical quantity of capital, but the ratio of the value of the surplus related to the value of the initial capital. Consequently the question of the value of the initial capital arises, and because the latter depends on the rate of profit, a circular reasoning begins, that marginalist theoreticians will not be able to overcome. This aggregation of different capitals at the national level into a single factor of production (the capital factor K) is nevertheless done in the *neoclassical aggregated function of production* (for instance in Solow, 1963).

This function of production is usually of the Cobb-Douglas type (Cobb and Douglas, 1928) :

$$Y = \varphi(L, K) = AL^{\alpha}K^{\beta} \tag{3.30}$$

With A, α and β the unknowns to be estimated, with the condition that $\alpha + \beta = 1$ so the function respects the hypotheses about homogeneity and linearity (Pasinetti, 2000). Equation 3.29 then becomes, if the land factor T is replaced by the capital factor K:

$$Yp = A\alpha L^{\alpha-1}K^{\beta}L + AL^{\alpha}\beta K^{\beta-1}K = AL^{\alpha}K^{\beta}(\alpha + \beta) \tag{3.31}$$

Parameter α then represents the part of national revenue that goes to the wages w, and β the part going to the profits π, if we are in a regime of free competition. Prices (profits and wages) then equal the marginal productivities. These parameters are calculated by the system (and are not, as we will see in the theory of Sraffa, partially exogenous): if the values are different (it would mean that we are not in a regime of free competition anymore), the system would be less efficient. The model then distributes fairly the revenues (accordingly with the marginal productivities) and allocates efficiently the resources, depending on the initial distribution of resources. If the initial distribution was unfair, a redistribution can be achieved through state intervention, which fulfills a social role (Meade, 1962).

[5] "Whoever be the entrepreneur (who maximises his own earnings), and whatever be the initial endowment of the production factors, a market with free competition will lead to such factors prices (i.e. to a wage rate and to a unit rent) which not only maximise the product, but also distribute to each factor of production precisely its physical marginal product, without leaving any (positive or negative) residual to anyone" (Pasinetti, 2000).

3.1.3.2 The Cambridge controversy

Pasinetti, after the empirical work of Sylos Labini (Pasinetti, 2000; Sylos Labini, 1995), criticizes the use of this kind of functions: most of the empirical studies shows that the sum of variables α and β is not equal to unity, when they should represent the shares of the revenue (whose value is set to unity). However, this is to be expected as we already saw that the rate of profit, which is supposed to remunerate the capital factor, is not a function of the input quantities of capital, but of their values. There is then an asymmetry between labor and capital factors: as soon as the system is producing more than one good, this asymmetry appears. There is a difference between the rate of profit and the marginal productivity of capital, which can be positive (Wicksell effect) or negative (inverse Wicksell effect, Wicksell, 1934).

A debate, called the Cambridge controversy, arose in the years 1950-1960's about the possibility to consider the capital as a unique factor of production, through the aggregation of heterogeneous means of production (Robinson, 1954). The conclusion was negative. Land and labor factors, considered as physical quantities, cannot be on an equal footing with a potential capital factor, considered in value. Furthermore, Sraffa's book (Sraffa, 1960) demonstrates the possibility of re-switching, i.e. that the choice of the more profitable technique, with an always increasing rate of profit, can bring back on use an obsolete technique. Thus Sraffa proves that there is no inverse monotonic relation between the rate of profit and the quantity of capital used. The neoclassical aggregated function of production is false: there is no simple relation between the physical quantity of the capital factor and its price (Pasinetti, 2000).

In mathematical terms, neoclassical economists made the hypothesis that $\frac{\delta\varphi}{\delta K} = \pi$ and that $\frac{\delta\varphi}{\delta L} = w$. As they usually assume that the function of production is in the form 3.30, the derivative regarding capital is represented in this way:

$$\frac{\delta\varphi}{\delta K} = \alpha\frac{L^{\beta}}{K^{1-\alpha}} \tag{3.32}$$

As soon as the quantity of capital therefore rises, the price of capital is supposed to decrease, with a stable quantity of labor. Inversely, as soon as the price of capital increases, the proportion of capital is supposed to decrease. However, Sraffa proves that there is no unequivocal link between the rate of profit and the quantity of capital used in the function of production 3.27: in general, $\frac{\delta\varphi}{\delta K} \neq \pi$.

After the Cambridge debate, all economists acknowledged that there was no monotonic relation between the ratio of the factors of production and the ratio of their prices:

> 'At the end of it, everybody had to agree that the assumption of diminishing returns to changing proportions, when applied to capital and labor, has no logical foundation. In general, there exists no monotonic association between variations in the *proportions* of capital to labor (or of capital to land or to capital to any non-produced

> factor of production) and the rate of profits. The implication is that the extension of the marginal principle to capital and labor (or to capital and land) has no logical foundation' (Pasinetti, 1999).

Nevertheless the use of this aggregated function did not disappear: Felipe and McCombie (2013) and Guerrien and Gun (2014) recently criticized the present use of Cobb-Douglas aggregated function of production in neoclassical models. Sraffa's model appears thus both as a reminder of the fact that the neoclassical theory started from an arbitrary interpretation of Ricardo's theory (the extension of the rent theory and its "law of decreasing returns" to all factors of production) and as a critique of the neoclassical theory of distribution (profits as the price of capital, wage, profits and rents determined in a technical way through the calculation of the marginal productivity of labor, capital and land), critique which is still relevant nowadays (Guerrien, 2012).

3.2 Sraffa

Sraffa considers that the marginal theory of value cannot apply in a static system, and this is why he discards it:

> "The marginal method requires attention to be focused on change, for without change either in the scale of an industry or in the 'proportions of the factors of production' there can be neither marginal product nor marginal cost. In a system in which, day after day, production continued unchanged in those respects, the marginal product of a factor (or alternatively the marginal cost of a product) would not merely be hard to find - it just would not be there to be found" (Sraffa, 1960, Preface).

Sraffa also rejects the relation between scarcity and value, because in a static system, scarcity also disappears.

Hence he constructed a theory of value that does not need any change to apply and thus that could apply for a static system,[6] grabbing inspirations from the classical authors. From Quesnay, he takes the idea of an economy seen as a circular process: commodities are produced from natural resources and existing capital, then they are sold as consumption or capital goods and the value of the surplus (after the replacement of used capital) is distributed to the different classes of population, capitalists, workers and rentiers. After that, the process is repeated. From Ricardo, he takes and expands the idea that some industries, as the corn sector in Ricardo's model, can be used to calculate the distribution variables (that will apply in all the economy), independently of the condition of production in other industries. He also pursued and achieved Ricardo's search for an invariant measure of value when the distribution variables are changing. And finally from Marx, he takes the idea that a maximum rate of profit should exist if wages are equal to zero and, from Smith and Torrens, the idea that fixed capital could be seen as a joint product which remains in the same industry at the end of the period of production (Sraffa, 1960, Appendix D).

The result is in total contrast with the marginalist analysis (Sraffa, 1960, Pasinetti, 1975, p. 193-197): in Sraffa's model, commodities are produced, they are not given in the beginning of the period. Their value does not emerge from their relative scarcities but from the commodities and the labor needed for their production. Prices do not reveal the marginal productivity of each factor but are the expression of the labor needed to perform the production, and are influenced by the distribution of the national revenue between profits and wages. If a good is more demanded, it will be more produced; his price may change or not, may rise or decrease, depending if there are constant, increasing or decreasing returns to scale, or if there is a change in the methods of production.[7]

[6] But not only! Some readers of Sraffa fall into the trap that Sraffa's analysis would only work for static systems, without technical change (see for instance Perez, 1980).

[7] Sraffian prices therefore do not act as indexes of equilibrium between offer and demand:

3.2.1 Initial assumptions

Sraffa looks at exchanges of commodities which are "produced by separate industries and exchanged for one another at a market held after the harvest" (Sraffa, 1960, § 1) . He is therefore dealing with a capitalist system of production, with industries that are specialized in the production of few commodities, and that need to exchange their products in order to get a revenue.

For instance Sraffa takes the following system:

$$\begin{array}{c} 280\,qr.\,wheat + 12\,t\,iron \rightarrow 400\,qr.\,wheat \\ 120\,qr.\,wheat + 8\,t\,iron \rightarrow 20\,t\,iron \end{array} \tag{3.33}$$

Then, at the end of the period of production (at the end of "the harvest"):

> "each commodity, which initially was distributed between the industries according to their needs, is found at the end of the year to be entirely concentrated in the hands of its producer. There is a unique set of exchange-values which if adopted by the market restores the original distribution of the products and makes it possible for the process to be repeated" (Sraffa, 1960, § 1).

Sraffa's intention is therefore to calculate the exchange ratios, which he will later called "prices", that would allow the process of production to operate once more. Thus prices in Sraffa really express the conditions of production during one period. They do not reveal the changes of production that could happen (because of a change in demand, for instance) between different periods. It is important to understand that Sraffa is not looking at what really happens in the market, but at what happens during the production process: maybe the system will not reproduce itself. However, if the system is to reproduce itself, Sraffa's method is able the calculate the prices that would prevail, just by looking at the conditions of production.

There is only one possible set of prices (exchanges) if there is no surplus, as in system 3.33. As soon as there is a surplus, there is an infinite possibility, as the surplus could be distributed in many ways to the several industries, each time modifying the prices, without changing the possibility for the system to reproduce itself. Sraffa assumes that this surplus must "be distributed in proportion to the means of production (or capital) advanced by each industry" (Sraffa, 1960, § 4) and that the rate of profits is equal for all industries: : "the distribution of the surplus must be determined through the same mechanism and at the same time as the prices of commodities. Accordingly we add the rate of profit (which must be uniform for all industries) as an unknown" (Sraffa, 1960, § 4). Furthermore, he states that labor is remunerated if the

it is only after a change in production (or a change in distribution) that a price can change, not because demand has changed. However, one may ask: how then is it possible to know when effective demand is not satisfied? This can be done through a price mechanism (for instance the market price of one commodity could differ from its Sraffian price, and that would mean that the commodity is less or more demanded than it has been produced), but this is outside the scope of the Sraffian theory.

form of wages, which are also a share of the surplus (the surplus is divided between profits and wages - rents will be introduced later, see subsection 4.2.3).[8] Looking at quantities of labor and commodities used by each industry during the period of production, Sraffa then calculates the prices.

3.2.2 The system in single production

Sraffa's system of value can be represented as follows, when each process produces only one commodity, and when each commodity is produced by only one process:[9]

$$\mathbf{Ap}\,(1+\pi) + w\mathbf{l} = \mathbf{Bp} \tag{3.34}$$

With $\mathbf{A}$ the matrix of dimension n, n with the quantities of each resource (in column) consumed by each industry (in rows), $\mathbf{B}$ the diagonal matrix of dimension n, n with, in the main diagonal, the quantities of each resource (in column) produced by each industry (in rows), $\mathbf{p}$ the column vector of the n prices, $\mathbf{l}$ the column vector of the n quantities of labor needed in each industry, w the wage per unit of labor (corresponding to the share of the surplus which goes to wages, divided by the total quantity of labor), and π the rate of profit (value of net production divided by the value of inputs).

Sraffa works only with unique systems where there is at least one basic commodity: "we shall assume throughout that any system contains at least one basic product" (Sraffa, 1960, § 6). One commodity (or one process) is basic if, when its production stops (or its activity level falls to zero), all the system collapses. If the system does not collapse, either the commodity is non basic or we have two independent systems that do not exchange commodities from each other (in this case, an exchange rate has to be arbitrarily fixed).

We know that all commodities are basic if matrix $\mathbf{A}$ is not reducible, i.e. if, through permutations of rows and columns, matrix $\mathbf{A}$ cannot be written as (Pasinetti, 1975, p. 106-113):

$$\mathbf{A} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \dots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{s1} & \mathbf{A}_{s2} & \dots & \mathbf{A}_{ss} \end{bmatrix} \tag{3.35}$$

With the sub-matrices on the main diagonal $\mathbf{A}_{ii}$ not reducible. If matrix $\mathbf{A}$ is not reducible, then all commodities are basic commodities (all processes are interdependent).

[8] We see that he is describing a capitalist system of production: capitalists ask for profits and workers sell their labor, which becomes, in the Marxist terminology, an "abstract, socially necessary labor" (Burkett, 2006, p. 184).

[9] In the case there are several processes producing the same commodity, a rent will appear: this case will be dealt with in subsection 4.2.3. The case of joint production is dealt with in subsection 3.2.4.

If matrix $\mathbf{A}$ is reducible, but all sub-matrices on the first column $\mathbf{A}_{i1}$ have at least one strictly positive element, then the commodities in the columns that composed the sub-matrices $\mathbf{A}_{i1}$ are all basic goods, and the other are non-basics.[10] In that case, the system is a unique one, i.e. it is not a juxtaposition of two different systems. If the system is actually a juxtaposition of different systems of production, a unique standard system, and thus a unique set of strictly positive prices, cannot be found.

This explains why Sraffa's prices do not represent the costs of production:

> "it is desirable at this stage to explain why the ratios which satisfy the conditions of production have been called 'values' or 'prices' rather than, as might be thought more appropriate, 'costs of production'. The latter description would be adequate so far as *non*-basic products were concerned, since ... their exchange ratio is merely a reflection of what must be paid for means of production, labor and profits in order to produce them - there is no mutual dependence. But for a basic product there is another aspect to be considered. Its exchange ratio depends as much on the *use* that is made of it in the production of other basic commodities as on the extent to which those commodities enter its own production ... A less one-sided description than cost of production seems therefore required. Such classical terms as 'necessary price', 'natural price' or 'price of production' would meet the case, but value and price have been preferred as being shorter and in the present context (which contains no reference to market prices) no more ambiguous' (Sraffa, 1960, § 7).[11,12]

The wage per unit of labor is also considered uniform in each industry: this can be understood if the quantities of labor, expressed in vector $\mathbf{l}$, are adequately chosen in order to respect the differences in salary that occurs in the real world. However, in that case it means that relative wages are supposed to be known (see Sinha, 2015 on this point). Actually, Sraffa shows that in order to solve

[10] Sraffa gives the following definition of a non-basic good: in a matrix $\mathbf{A}$ of dimension n, $2n$, with n processes in rows and n goods in columns, with at first the coefficients of inputs, and then the coefficient of outputs, if a good (or a group of goods) appears in k rows, and that in these k rows, the number of linearly independent rows is not higher than 1, then this good (or this group of goods) is non-basic (Sraffa, 1960, § 60). Inversely, if the number of linearly independent rows is higher than 1, this good is basic.

Thus, in order to be non-basic, the matrix composed of these k rows and $2n$ columns should be of a rank lower or equal to 1. In Sraffa's system, there is the assumption that at least one basic good exists, i.e. one good is used as an input in two linearly independent processes.

[11] Again we see that even if Sraffa considers a real system, its prices are not the market prices, i.e. not the real prices.

[12] Sraffa furthermore adds, about "cost of production" and "capital", that "these terms have come to be inseparably linked with the supposition that they stand for quantities that can be measured independently of, and prior to, the determination of the price of products' (Sraffa, 1960, § 7). According to him this supposition leads to the circular reasoning exposed in subsection 3.1.2.3, this is why he also rejects them.

system 3.34, one of the distribution variable, the wage or the rate of profit, must be given.[13] If one commodity is the numeraire (i.e. if its price is set to one), we still have $n-1$ relative prices, plus π and w as unknowns, and only n equations: it is not possible to solve the system, unless another variable is given in an exogenous way.

3.2.3 The standard system

With the convention that a uniform rate of profits is applied to all industries, the system can be rescaled without changing the rate of profits. However, this rate is not independent from the prices. However, Sraffa shows that a particular rescaling, which eliminates the non-basic industries and which is called the standard system, helps to reveal that the maximum rate of profits is independent from the prices (the rate of profit is maximum when the wage is set to zero). The maximum rate of profits of the system can be calculated without knowing the prices, and if the numeraire is the standard commodity (a composite commodity made up with the commodities that are produced in surplus in the standard system), a linear relationship between the wage and the rate of profits can be calculated, still without knowing the prices. Distribution thus appears to be independent from the process that assesses the prices.

Sraffa makes the same convention concerning non-basic industries than concerning basic industries: the rate of profit that will apply will be the uniform rate of profit that applies for the production of basic commodities (and the prices of the non-basic goods, that are cost of production prices, can be calculated). However this convention is not always possible: in some cases, the rate of profit of the non-basic process has to be lower than the uniform rate of profit. For instance, if the non-basic commodity is used by its own process of production, a maximum rate of profit appears for this process, and this rate could be lower than the uniform one.[14] Sraffa (1960, Appendix B) gives an example with beans production: in this case, the maximum rate of profit of the beans production is 10%, whereas the uniform rate of profit is 15%. Either the rate of profit is then lower in the bean process, or the assumption that each commodity receives a unique price must be relaxed: if the beans which are sold as an output are more expensive that the beans that enter the beans production process, then the rate of profit could reach 15%.

The method to construct the standard system and to calculate the prices is the following.

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[13] He lets open the possibility of a choice between the two variables. He incidentally says that the rate of profit can be determined "... in particular by the level of the money rates of interest" (Sraffa, 1960, § 44). But this sentence should not be interpreted as a decisive preference from Sraffa, but more as an example in the course of his development (see Pasinetti, 1988b on this point).

[14] Lévy and Duménil (1982) define this situation as a situation of "surclassement".

3.2.3.1 Elimination of the non-basic commodities and a uniform physical rate of profit

Firstly, the labor coefficients are transformed so that the sum of all new labor coefficients equals to one:

$$\mathbf{el}^* = 1 \tag{3.36}$$

In order to do so, all labor coefficients are divided by the total labor, which is the sum of the initial labor coefficients:

$$\mathbf{el} = L \tag{3.37}$$

$$\mathbf{l}^* = \frac{\mathbf{l}}{L} \tag{3.38}$$

With this convention, the wage w and the share of the value of the surplus which is distributed to wages, written ω, become equal.

Secondly, the non-basic commodities are eliminated, in order to construct a system with only interdependent processes, which is called the standard system. Through permutations of rows and columns, matrix $\mathbf{A}$ is written :

$$\mathbf{A} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{0} & \dots & \mathbf{0} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \dots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{s1} & \mathbf{A}_{s2} & \dots & \mathbf{A}_{ss} \end{bmatrix} \tag{3.39}$$

The system is then multiplied by the row vector $\mathbf{q} = \begin{bmatrix} \mathbf{q}_1^* & \mathbf{0} & \cdots & \mathbf{0} \end{bmatrix}$, with the two conditions that total labor is still equal to one (in this way the value produced by the standard system is still equal to the value produced by the real initial system):

$$\mathbf{q}_1^* \mathbf{l}^* = 1 \tag{3.40}$$

And that a uniform physical rate of profit is found:

$$\mathbf{q}_1^* \mathbf{A}_1 (1 + \Pi) = \mathbf{q}_1^* \mathbf{B}_1 \tag{3.41}$$

Thus the standard system is written in this way:

$$\mathbf{q}_1^* \mathbf{A}_1 \mathbf{p} (1 + \pi) + \omega = \mathbf{q}_1^* \mathbf{B}_1 \mathbf{p} \tag{3.42}$$

The uniform physical rate of profit can always be found, in a system of basic commodities; and this physical rate is also the maximum rate of profit, i.e. the rate of profit that appears when all the surplus is given to the profits. When $\omega = 0$, Eq. 3.42 becomes equal to Eq. 3.41, because vectors of prices can be removed.

3.2.3.2 Three specificities of the standard system

In the standard system, the uniform rate of profit is the same as the initial system. The standard system is constructed by multiplying each process by a specific coefficient, which applies to the inputs and to the outputs. Thus returns to scale are retained for all processes. The second particularity of the standard system is that we know the range of the possible uniform rates of profit: the uniform rate of profit cannot be higher than the physical rate of profit, which can be known without knowing the prices. Finally, the third specificity of the standard system is that, if the standard commodity is chosen as the numeraire, the relation between the rate of profit and the wage becomes independent from the prices. The standard commodity is a composite commodity which aggregates the net production of the standard system. If it is chosen as the numeraire, we have:

$$\mathbf{q}_1^* \left(\mathbf{B}_1 - \mathbf{A}_1\right) \mathbf{p} = 1 \tag{3.43}$$

And then Sraffa proves that the relation between the shares of the value of the surplus given to the wages and the profits becomes:

$$\pi = \Pi \left(1 - \omega\right) \tag{3.44}$$

If an other numeraire is chosen, the prices will still ensure the reproduction of the system of production. But this simple relation between the distribution variables will be hidden.

Once the prices of production are calculated, we can come back to the initial real systems, and find the prices of non-basic commodities.[15]

Let us come back to the initial convention about the uniformity of the rates of profit. In the standard system, the aggregated maximum rate of profit of the system can be known without knowing the prices. Knowing this maximum rate of profit, we can find the relation between the rate of profit and the wage (it is an inverse linear relationship, once the standard commodity is chosen as the numeraire). However, the standard system can only be constructed if we previously apply this convention to the initial system: then only the rescaling that must be done in order to find the standard system does not impact the aggregate rate of profit. This is the only reason why Sraffa chooses this convention over the infinity of possible conventions about the distribution of the surplus.

3.2.4 Joint production: prices positivity, Manara's problem

Joint production arises when one process produces more than one commodity. Joint production is very important for economic and environmental analysis (see for instance Kurz, 2006), and Sraffa devoted the whole second part of his book (out of only three) about this case. However he seems to have been merely

[15] Again we can see that a change in the conditions of production of non-basic commodities will not influence the prices of basic commodities.

interested in two applications of joint production, fixed capital and land (this last application case will be dealt with in Section 4.2), as reported by Schefold:

> "When [Sraffa] was confronted with the difficulties of joint production systems, which had surfaced in the 1960s and early 1970s, he told me that, if he had known, he should have written much less about general joint production systems and more about fixed capital and land, and that he would have liked to treat only part of the problematic of joint production and, finally, that it might have been better to begin the exposition with the analysis of fixed capital, followed only by some thoughts on joint production in general. ... The discussions on joint production in general, which were conducted in the 1970s and 80s, would probably not have been avoided altogether, but one might look at them in a different light today: they would perhaps appear as excursions into a strange and not entirely relevant territory somewhat removed from the core of classical theorizing" (Schefold, 2005).

Consequently, I will only deal in this part with two points (fixed capital and the possibility to find a standard system for any joint production system) and I will encourage the reader to discover more specialized authors if he wants to learn more about general joint production (for instance Schefold, 1989; Kurz and Salvadori, 1995).

3.2.4.1 Fixed capital

Sraffa shows that joint production could help to take into account fixed capital as a means of production: a machine will enter the process as an input, like energy and raw materials, and will come out as a joint product at the end of the period of production, an older and more damaged product than in the beginning of the period. This means that, depending on its age, a machine will have a different price, and thus should be treated as a different product. A process using a machine with a life-span of five years can then be divided into five different processes, each time with a different machine because of its age - and the last period, the joint product will be scraped metal.

The usual method to take into account fixed capital depreciation is the following one:

$$Annual\ charge = p_{m_0} \frac{r\,(1+\pi)^n}{(1+\pi)^n - 1} \tag{3.45}$$

With p_{m_0} the price of the new machine, π the rate of profit and n the number of years measuring the machine life-span. With joint production, we write the different processes that can produce a quantity G of commodity g:

$$\begin{aligned}
(M_0 p_{m_0} + A_g p_a + \ldots + K_g p_k)(1+\pi) + L_g w &= G p_g + M_1 p_{m_1} \\
(M_1 p_{m_1} + A_g p_a + \ldots + K_g p_k)(1+\pi) + L_g w &= G p_g + M_2 p_{m_2} \\
&\cdots \\
\left(M_{n-1} p_{m_{n-1}} + A_g p_a + \ldots + K_g p_k\right)(1+\pi) + L_g w &= G p_g
\end{aligned} \tag{3.46}$$

With M_i the machine which is i years old, with a life-span of n years. In this system, all inputs and outputs coefficients are the same in all processes, except for the machines: thus it means that a constant efficiency is assumed. We can find again the equation of the annual charge, through normalisation and by adding the different equations:

$$M_0 p_{mo} \frac{r\,(1+\pi)^n}{(1+\pi)^n - 1}\,(A_g p_a + \ldots + K_g p_k)(1+\pi) + L_g w = G p_g \tag{3.47}$$

But Sraffa warns that Eq. 3.47 can only be used if the assumption of constant efficiency of the machine is taken. A more general formulation should allow an annual charge which could vary over time, in the following way:

$$Annual\ charge = M_i p_{m_i} - M_{i+1} p_{m_{i+1}} + M_i p_{m_i} r \tag{3.48}$$

Salvadori and Steedman (1988), following Schefold (1976; 1980), show that if old machines are the only joint products, if each process is using only one machine and if each machine is only used by one process, we can always find a set of positive prices. Salvadori (1988) then extends this result to the cases where the same machine is used by several processes, where one process uses several machines and where scrapped machines are recycled (they are used as inputs in order to produce new machines).

3.2.4.2 Manara's problem

Manara (1980) shows that the construction of the standard system is not always possible in the realm of real space when general joint production is allowed: thus a set of basic commodities with strictly positive prices may not be found. Dupertuis and Sinha (2009) try to show that this is actually not the case: it is always possible, for any given system of joint production (even if it is not "square", i.e. with different numbers of processes and commodities), to reduce it into a system of basic commodities. The difficulty arises in the definition of commodities in a joint production system.

According to Dupertuis and Sinha, commodities are what is exchanged by the system at the end of the period of production. In the case of single production, what is exchanged is necessarily produced by only one process. However, in the case of joint production, what is exchanged may be a composite commodity, instead of a single commodity. Let us have, for instance, a system with two processes, with $\mathbf{A}$ the inputs matrix and $\mathbf{B}$ the outputs matrix:

$$\mathbf{A} = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}; \quad \mathbf{B} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{3.49}$$

Here the exchanges at the end of the production period are clear: process 1 exchanges one unit of its production (commodity 1) with one unit of the production of process 2 (commodity 2). But now with joint production, we could have this kind of system:

$$\mathbf{A} = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \end{bmatrix}; \quad \mathbf{B} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 2 \end{bmatrix} \tag{3.50}$$

A new resource (commodity 3) has appeared, which is produced by process 2. This resource is apparently a basic one. However, the exchanges at the end of the period of production are as follows: process 1 gives one unit of commodity 1 and receives in exchange one unit of commodity 2 and one unit of commodity 3. Thus, for the system, commodities 2 and 3 are one composite commodity. By adding them together, we can find back system 3.49. This is done by multiplying system 3.50 by a transformation matrix in the form:

$$S = \begin{bmatrix} 1 & 0 & -1 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{bmatrix} \tag{3.51}$$

In this way commodity 1 will remain the same, commodity 2 will become a composite made up by one unit of previous commodity 2 and one unit of commodity 3, and commodity 3 will remain the same. The result will be:

$$\mathbf{A} = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix}; \quad \mathbf{B} = \begin{bmatrix} 1 & 0 & -1 \\ 0 & 1 & 1 \end{bmatrix} \tag{3.52}$$

Commodity 3 then disappears from the means of production and from the outputs, and we remain with a system of basic commodities, where the second one is a composite commodity.

We could have also the following kind of system:

$$\mathbf{A} = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}; \quad \mathbf{B} = \begin{bmatrix} 1 & 3 & 2 \end{bmatrix} \tag{3.53}$$

This is for Dupertuis and Sinha a "disguised one-good 'corn' economy" (Dupertuis and Sinha, 2009). The usual method to solve this kind of systems is to add two independent processes that use and produce the same commodities as the first process, but with different proportions. But as the first process is self-reproducible, the resulting system will not be composed of interdependent processes (the first one will remain independent from the two others). Thus the right method is to successively transform the system with, each time, a commodity composed of one unit of the three previous commodities, and two different previous commodities (first, the composite commodity and commodities 1 and 2; then the composite commodity and commodities 1 and 3; and finally the composite commodity and commodities 2 and 3). The system with the lower profit rate will be the chosen one.

By aggregating the commodities into composite commodities that are actually exchanged by the system, by eliminating hidden self-reproducible processes, and by eliminating processes which are the only ones to produce a specific non-basic commodity (Sraffa gives an example of processes of this kind, see Sraffa, 1960, § 59), Dupertuis and Sinha then show that it is actually always possible to construct a standard system, starting with any random joint production system. However, this does not mean that positive prices will be found for all commodities: once a positive price is found for a composite commodity, it is not possible to know how this price is decomposed in order to find the prices of the initial commodities.

3.3 Sraffa and classical economics: rather a new interpretation than a continuity

3.3.1 Gravitation prices?

A common view of Sraffa's prices is that they are long term equilibrium prices, i.e. the result of a gravitation mechanism, because in Sraffa's theory, the rate of profit is always uniform. In classical economics, prices are supposed to gravitate around prices of production, or natural prices: free competition ensures that less profitable techniques are eliminated, which leads to one uniform price for each commodity and one uniform rate of profit for all sectors.[16]

In the gravitation mechanism, the first step is to assume that effective demand (or social demand) can be satisfied through the available techniques and the available quantity of human labor. If the effective demand is not satisfied in one sector, the relative price of the commodity produced in that sector will increase. The rate of profit will then increase in that sector. A movement of labor and capital follows, from sectors in excess supply to sectors in excess demand. This movement will help sectors in excess demand to increase their production. The relative prices of those commodity will then decrease, whereas they may rise in the sectors where the production has fallen under the effective demand level. The rate of profit will then fall in the first sectors, and rise in the second, and a new movement of capital and labor will follow.

These successive movements will end when the effective demand will be exactly satisfied: at this point, the rates of profit are assumed to be uniform. It is to be noted that all changes in production assume constant returns to scale (even if the assumption is not stated, all examples in classical economics show constant returns to scale, see Sinha and Dupertuis, 2009 on that point).

The problem with this gravitation process is that it does not work anymore if more than 2 sectors are involved. Sinha and Dupertuis (2009), following the seminal work of Steedman (1984), show that even with constant returns and a non-growing labor force, if more than one sector is not in equilibrium, the simultaneous adjustments will not, in general, guide the system to a price vector where, at the same time, effective demand is satisfied and rates of profits are uniform. The process of gravitation may never ends, because:

1. Prices and rates of profit will not necessarily change in the same direction;
2. Prices may not rise with excess demand and fall with excess supply (adjustments are not simple)
3. There is no guarantee that rates of profits will be equal when the effective demand will be satisfied.

[16] See for instance Lévy and Duménil (1982): "que la technique soit telle que l'affectation du travail aux produits soulève ou ne soulève pas de problèmes, on sait qu'en production capitaliste les marchandises n'ont aucune raison de s'échanger à des prix proportionnels aux valeurs. Par contre, on peut envisager un état idéal de la concurrence tel que la mobilité du capital aboutisse à l'équirémunération des capitaux et du travail, c'est-à-dire à la formation de prix de production".

Sinha and Dupertuis (2009) actually demonstrates that the only case where the process always finds an equilibrium is when relative prices are fixed (i.e. constant returns to scale are assumed), rates of profits are uniform, and only quantities change, i.e. the case where the initial prices and rates of profit are in an equilibrium position.

3.3.2 Sinha: the new interpretation

Sraffa's uniform rate of profit is actually a convention, which allows him to construct a standard system (see subsection 3.2.3). This is not an assumption about the real system, which could have several different rates of profit, but a convention which helps Sraffa to reveal how the distribution of the surplus influences the prices.

3.3.2.1 Argument against the gravitation process

Sinha argues that the gravitation mechanism is not included in Sraffa's theory.

First, he underlines that returns to scale are not assumed to be constant in Sraffa (Sinha, 2007): they could, but actually Sraffa is not considering any change in the quantity produced. Sraffa begins precisely his book by explaining this point:

> "Anyone accustomed to think in terms of the equilibrium of demand and supply may be inclined, on reading these pages, to suppose that the argument rests on a tacit assumption of constant returns in all industries. ... In fact, however, no such assumption is made. No changes in output and ... no changes in the proportions in which different means of production are used by an industry are considered, so that no question arises as to the variation or constancy of returns. The investigation is concerned exclusively with such properties of an economic system as do not depend on changes in the scale of production or in the proportions of 'factors"' (Sraffa, 1960, Preface).

A confirmation of this can be found in his letter of December 9, 1964 to Arun Bose, after the latter assumes in a previous letter that demand plays only a passive role in Sraffa's system:

> "I am sorry to have kept your MS so long—and with so little result. The fact is that your opening sentence is for me an obstacle which I am unable to get over. You write: 'It is a basic proposition of the Sraffa theory that prices are determined exclusively by the physical requirements of production and the social wage–profit division with consumers demand playing a purely passive role'. Never have I said this: certainly not in the two places to which you refer in your note 2. Nothing, in my view, could be more suicidal than to make such a statement. You are asking me to put my head

> on the block so that the first fool who comes along can cut it off neatly. Whatever you do, please do not represent me as saying such a thing" (Sraffa's notes, P C32, cited in Sinha, 2007).

If demand were changing, the produced quantities would change. Prices would then change if returns are not constant. Thus assuming that demand plays a passive role involves the assumption of constant returns to scale, an assumption that Sraffa refuses. And even if the standard system is constructed by applying constant returns to scale to the different processes, it should be remembered that it is just a theoretical construction ("a purely auxiliary construction", Sraffa, 1960, § 43) whose goal is to "give transparency to a system and render visible what was hidden" (Sraffa, 1960, § 31).

Sinha then shows that Sraffa is not considering a system in an equilibrium position: "Sraffa had taken a philosophical or methodological position that the theoretical understanding must be built on only things that are ideally observable and, thus, no subjective element (such as 'inducement') should enter his equations" (Sinha, 2012). Thus he only wants to deal with real situations, by looking at present real economic systems.[17] A good confirmation of this statement can be found in the draft preface of his book that Sraffa wrote in 1957:

> "This is not proposed as a complete system of equilibrium. The data assumed are not sufficient to determine either distribution or values. Only the effects of hypothetical, arbitrarily assumed extra data (such as wages, or the rate of profits) are discussed. ... It is offered as a preliminary and there is no a priori reason why, on the basis of it, an equilibrium system should be built: there is some room left for it, as this is confessedly indeterminate; but the question is whether there is room enough for the marginal system. (D3/12/46:20, dated 2 April 1957, cited in Sinha, 2013)

3.3.2.2 Argument against the equilibrium rate of profit

Sraffa describes this system of value, in a note from 1927-1931, in this way:

> "The significance of the equations is simply this: that if a man fell from the moon on the earth, and noted the amount of things consumed in each factory ... during a year he could deduce at which values the commodities must be sold, *if* the rate of interest

[17] Another note from Sraffa shows his willingness to be dependent only on inputs of circulating capital to assert prices: "Why do we want to reduce Fixed Cap. to Circulating Capital? Because we must prove that the only quantities whose knowledge is required to determine prices are the Capital Inputs; while the Capital Stock is not required, and anyhow is only a derived quantity, derived from the inputs" (Sraffa's notes, D3/12/27: 46 (1 – 5) ..., cited in Kurz and Salvadori, 2005). Ideally prices should not therefore be inferred from subjective appreciation, but only from observable data (quantities exchanged). He was so determined in this direction that he was even reluctant to use the amortisation technique on fixed capital (see Kurz and Salvadori, 2005 on this point).

> must be uniform and the process of production repeated. In short, the equations show that the conditions of exchange are entirely determined by the conditions of production. (D3/12/7, emphasis added, cited in Sinha, 2012).

But Sinha notes that in Sraffa's book, the term "if" has disappeared: "we add the rate of profit (which must be uniform for all industries) as an unknown ..." (Sraffa, 1960, § 4). This change, for Sinha (2012), has been caused by Sraffa's discovery of the standard system in the 1940s.

In this kind of system made up only by basic commodities and basic industries, the maximum rate of profit appears to be given by the conditions of production, independently from the prices. And this system produces the standard commodity, which is the only commodity whose price is not affected by a change of distribution, and which, if taken as the numeraire, allows the relationship between rate of profits and wage to be linear. Thus the convention of a uniform rate of profits is justified: with this convention the standard system can be constructed, and we can prove that the rate of profit is a non-price phenomenon, but a physical consequence of the fact that the system is producing a surplus. Furthermore, with this standard system, distribution can be known prior to prices, and thus also appears as a non-price phenomenon: it is a political one.[18]

As the real system is composed of the same equations multiplied by a positive real coefficient, the rates of profit and the prices are not changed during the construction of the standard system. However, the aggregated maximum rate of profit (the rate of profit of the addition of all processes, with wage equals to zero) will be different. Only if the rate of profits are already uniform in the real system, the maximum aggregated rate of profits will be the same in the real and in the standard system.

Let us look at the following real system of production, with only basic commodities and basic industries (we have the same system in Sraffa, 1960, § 25) :

$$\begin{array}{r} 90\, iron\ + 120\, coal\ + 60\, wheat\ + \frac{3}{16}\, labour\ \rightarrow 180\, iron \\ 50\, iron\ + 125\, charbon\ + 150\, wheat\ + \frac{5}{16}\, labour\ \rightarrow 450\, coal \\ 40\, fer\ + 40\, charbon\ + 200\, wheat\ + \frac{8}{16}\, labour\ \rightarrow 480\, wheat \end{array} \tag{3.54}$$

[18] This fact that the uniform rate of profit is a convention was also pointed out by Hicks:

> "Sraffa leaves us to find out what his prices are, but I doubt if they are equilibrium prices. They seem to be prices which are set upon products, by their producers, according to some rule. Now it is perfectly true that we are nowadays familiar with that method of price-fixing, by "mark-up"; but when that method is used, the rate of profit that is used to establish the mark-up is conventional. Now it may be that Sraffa wants us to think of his rate of profit as being conventional; and that the uniformity of the rate of profit throughout his system, of which he makes so much, is just a uniformity of convention" (Hicks, 1985, cited in Sinha, 2012).

The price system of Sraffa is the following one:

$$\begin{array}{r} (90p_i + 120p_c + 60p_w)\,(1 + r_i) + \frac{3}{16}w = 180p_i \\ (50p_i + 125p_c + 150p_w)\,(1 + r_c) + \frac{5}{16}w = 450p_c \\ (40p_i + 40p_c + 200p_w)\,(1 + r_w) + \frac{8}{16}w = 480p_w \end{array} \tag{3.55}$$

If the wage is given from outside, for instance set to zero, and if one price is used as the numeraire, we are left with 5 unknowns and 3 equations. Thus the system cannot be solved. Furthermore we see that the aggregated maximal rate of profit depends on the prices:

$$R = \frac{165p_c + 70p_w}{180p_i + 285p_c + 410p_w} \tag{3.56}$$

However, it is possible to construct a standard system by multiplying all equations without modifying total labor, so each good appears in the same proportion in the inputs and in the surplus:

$$\begin{array}{r} 120\,iron\ + 160\,coal\ + 80\,wheat\ + \frac{1}{4}\,labour\ \rightarrow 240\,iron \\ 40\,iron\ + 100\,coal\ + 120\,wheat\ + \frac{1}{4}\,labour\ \rightarrow 360\,coal \\ 40\,iron\ + 40\,coal\ + 200\,wheat\ + \frac{2}{4}\,labour\ \rightarrow 480\,wheat \end{array} \tag{3.57}$$

Thus we see that the average maximal rate of profit of the standard system does not depend on prices anymore:

$$G = \frac{40\,iron\ + 60\,coal\ + 80\,wheat}{200\,iron\ + 300\,coal\ + 400\,wheat} = \frac{1}{5} \tag{3.58}$$

Now the only possible set of prices which ensures that $R = G$ is the set of price which ensures that the rates of profit are uniform in the real system. If the wage becomes positive, that does not modify this finding. If we pay the wage in the standard commodity, the proportion of each good between the surplus and the inputs will remain uniform. And if the numeraire is the standard commodity, i.e. here $40p_i + 60p_c + 80p_w = 1$, we see that there is a linear relation between the wage and the average rate of profit:

$$r = R(1 - w) \tag{3.59}$$

After the publication of his book, Sraffa wrote that: "the wage and the aggregate profit of reality are, at best, rough approximations of the standard wage and profit. But the rate of profit of reality is identical to that of the standard" (PSP, D3/12/111/139, cited in Sinha, 2012). The 'rate of profit of reality' can only mean the rate of profit that we will find if we apply the convention that the rate of profits are uniform. By applying this convention, Sraffa is just looking at the economic properties of the real system of production:

> "Now I am not assuming any forces: I simply say that, if the values will in reality be as given by the equations certain conditions

will be satisfied if not they will not be satisfied. In this case, profits will bear different proportions to capital in different industries. Since this happens to a considerable extent in reality, this means that the values in the market will be different from those in the equations." (D3/12/7, note from 1928, cited in Sinha, 2012).

3.3.3 Sraffa's theory of value and the relation with Marx's labor theory of value

Sraffa assumes that the value of outputs equals the value of inputs. If the output is in excess vis-à-vis the inputs, the difference between both quantities (i.e. the surplus) is distributed between profits and wages; then the value of the outputs covers the value of the inputs plus the wages and the profits. Thus the value depends on the conditions of production, and on the distribution. It expresses those ratios that are necessary in order to repeat the production process and to distribute the surplus according to a rule which is given from the outside. The theory of Sraffa allows us to make a clear distinction between three different economic questions:

1. The question of the forces behind the present conditions of production (determinants of investments and technological change)
2. The question of the forces behind the present distribution of the surplus (power relations between classes)
3. The question of the value of the commodities.

Sraffa answers only the third point, and shows that the answer depends on the two first point : once conditions of production and distribution are given, it is possible to calculate the values of each commodity. His theory of value is similar to the cost theory of value developed by the Classics, and especially by Petty and the Physiocrats (Garegnani, 2005).

There is only one condition for a commodity to have a value:

- It must be produced, i.e. at least one valued commodity (owned by an agent) must be consumed in order to get the commodity. A commodity which is not produced bears no price and thus must not be represented in the value system (unless it supports a differential rent, see subsection 4.2.3).

Theoretically a commodity can have a value even if no labor is used for its production: in system 3.33, used by Sraffa in the beginning of his book, there are no labor coefficients. However, in all the subsequent examples used in his book, Sraffa uses labor coefficients for all processes. And he explains that, if previously no labor coefficient were used, it was because: "we have up to this point regarded wage as consisting on the same footing as the fuel for the engines or the feed for the cattle" (Sraffa, 1960, § 8). Thus even in the first system of his book, labor was needed in order to produce the commodities. The two conditions for a commodity to have a value can then be rephrased in this way:

- It must be produced, i.e. at least some labor must be consumed in order to get the commodity.

As all production needs human labor, it is then possible to reduce all prices into amounts of labor. The prices solution, in system 3.34, is generally written:

$$\mathbf{p} = [\mathbf{I} - (1+\pi)\,\mathbf{A}]^{-1}\,\mathbf{l}w \tag{3.60}$$

In the case where $\pi = 0$ and if we take wage as the numeraire, i.e. $w = 1$, we get a simplified relation:

$$\mathbf{v} = \mathbf{p} = (\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{l} \tag{3.61}$$

With $\mathbf{v}$ the vertically integrated coefficients of labor, representing "quantities of labor directly and indirectly 'embodied' in each physical unit of the commodities which make up the net product of the economic system (what Marx called 'values', by definition)" (Pasinetti, 1975, p. 76).[19]

In this general case, it is possible to decompose the prices in the form of a power series:

$$\mathbf{p} = w\mathbf{l} + (1+\pi)\,\mathbf{A}\mathbf{l}w + (1+\pi)^2\,\mathbf{A}^2\mathbf{l}w + \ldots \tag{3.62}$$

Thus it is possible to resolve "the price of every commodity intro a sum of profit-weighted quantities of labor" (Pasinetti, 1973; Sraffa, 1960, Chapter VI). And Pasinetti (1973) shows that this decomposition into dated quantities of labor can also be constructed in the case of joint production.

Marx begins his analysis of value with the case of system 3.61. He then claims that the owner of the means of production (the capitalist) is in a privileged situation that allows him to pay a lower wage than the "complete" one (Pasinetti and Garbellini, 2014) : thus surplus value (or "unpaid wages") appears, and Marxian values change. Marxian values differ from Sraffian prices of production (as soon as the rate of profit differs from zero) because profits in Sraffa are paid proportionally to the capital (commodities and fixed capital used as inputs) and not proportionally to labor inputs (as the surplus in Marx). Thus, in general, the value of production and the value of the surplus is different in both systems, and the rate of surplus differs from the rate of profit. Marx incorrectly thought that each of the three expressions (prices, value of the surplus and rate of profits) would always be equal (Marx, 1959, pp. 42, 157, 164, quoted in Pasinetti and Garbellini, 2014): then a large literature follows on the problem of the transformation of Marxian values into prices of production. Recently, Pasinetti and Garbellini (2014) show that if we look at a standard system, each of the three expressions becomes equalities.

[19] It is to be noted that the 'values' depend on the accounting of labor coefficients. What is the measure of labor? Time could be used as a fair numeraire, but some works need more qualification than others, and, on this basis, could require a higher wage than others. See also Lévy and Duménil (2015) about the differences in wages, and the notion of a managerial class, which receives very high wages as a revenue (profits are distributed in the form of high wages), therefore a different class from the "poor" working class.

Both theories of value therefore seem to be close; furthermore Sraffa appears to have a good opinion of Marx's theory. He especially considers him as the last economist to have a full understanding of classical economics: "in the middle of the 19th century a man [Marx] succeeds, either by accident or by superhuman effort, in getting again hold of the classical theory: he improves it, and draws its practical consequences from it" (Sraffa's notes, D3/12/4: A5.14iii, cited in Garegnani, 2005). Furthermore Sraffa explains the incredible support to the marginalist paradigm in economic science because it was an attempt to contradict labor value theories, theories which can lead to Marxist ideas:[20]

> "This [the concepts of subjective costs and/or utility as ultimate standards] was an enormous breach with the tradition of Pol[itical] E[conomy]; in fact, this has meant the destruction of the classical P[olitical] E[conomy] and the substitution for it, under the old name, of the Calculus of Pleasure & Pain [. . .] When the Jevonsians turned back to write their own history, they found with pride (it ought to have been with disma[y]) that they had no forerunners amongst P[olitical] E.[conomists]; their forerunners were mainly two or three cranks, an engineer Dupuit, a mathem.[atician] Cournot, a Prussian civil servant Gossen, who had only cultivated P[olitical] E[conomy] as a hobby. [. . .] They had not the slightest knowledge of the works of the Classical economists. They drew it out of their fancy. In fact, no competent P[olitical].E[cono]mist, with a conscience of his tradition, would have degnato [in Italian in the text: deemed worthy] to entertain those views. What had happened in the meantime to change so much the mind of the economists, and induce them to scrap all that had been done up to that time? (It was in fact scrapping the whole: Jevons (1957) Preface, and Cannan, Theories [of Production and Distribution (1893), 379 – 83]. . .) Socialism has been the cause of all this. In fact classical P[olitical] E[conomy], with its surplus to be arbitrarily divided leads straight to Socialism" (Sraffa's notes, D3/12/4; A5.2.i, ivi, ii, Garegnani, 2005).[21]

[20] Guerrien and Gun (2014) also describe the attempt to show the existence of an aggregate function of production as an attempt to invalidate the Marxist theory of distribution (this is explicitly confessed in Clark, 1899 and Douglas, 1976).

[21] Some researchers defend the thesis that Sraffa's intention, while writing his book, was to rehabilitate Marx theory (see for instance De Vivo, 2001). To see a criticism of this thesis, see Garegnani (2005).

3.4 Differences between Sraffa's, Leontief's, Von Neumann's and general equilibrium models

Several authors link Sraffa's model with the works of Leontief (1941) on Input-Output models and Von Neumann (1946) on general equilibrium models. However, these works are actually quite far from Sraffa's analysis:

> "one cannot refrain from asking what conception Sraffa had of the economic movements of physical quantities, i.e. more specifically, of the dynamics of an economic system. It is tempting to make comparison with Von Neumann's scheme or with Leontief 's dynamic model to try to gather some clues. But in spite of the analytical similarities with Sraffa's 'standard system', Von Neumann's approach appears inappropriate and so does Leontief 's. Sraffa does not even mention Von Neumann's model, nor does he mention Leontief. Those who had the opportunity of putting questions to him on these similarities know Sraffa's negative responses. Von Neumann's and, even more so, Leontief 's approaches are quite alien to his conception of the movements of an economic system through time" (Pasinetti, 2012b).

Finally some neoclassical authors (such as Samuelson, 2008) think that Sraffa's theory represents a particular case of the neoclassical general equilibrium theory. Thus I will quickly presents all three approaches in order to grasp their differences with Sraffa's model.

3.4.1 The closed Leontief model

The input-output approach is developed by Leontief (1941): let matrix $\mathbf{A}$ of constant and positive technical coefficients $a_{ij} \geq 0$ be of dimension n, n.[22] This matrix defines the technology of a system in single production: on column i, we can read the direct quantities of inputs required to produce one physical unit of good i, and on row i we can see the different direct requirements in good i for the production of the different goods of the system. The closed Leontief model is constructed with the following two systems of equations:

$$\begin{cases} a_{11}Q_1 + a_{12}Q_2 + \ldots + a_{1n}Q_n \equiv Q_1 \\ a_{21}Q_1 + a_{22}Q_2 + \ldots + a_{2n}Q_n \equiv Q_2 \\ \vdots \\ a_{n1}Q_1 + a_{n2}Q_2 + \ldots + a_{nn}Q_n \equiv Q_1 \end{cases} \tag{3.63}$$

[22]This presentation of Leontief approach owes much to Pasinetti (1975).

$$\begin{cases} a_{11}p_1 + a_{21}p_2 + \ldots + a_{n1}p_n \equiv p_1 \\ a_{12}p_1 + a_{22}p_2 + \ldots + a_{n2}p_n \equiv p_2 \\ \vdots \\ a_{1n}p_1 + a_{2n}p_2 + \ldots + a_{nn}p_n \equiv p_1 \end{cases} \tag{3.64}$$

With Q_i the quantity produced of good i at each period and p_i the price of good i. We can write again systems 3.63 and 3.64 in their matrix form:

$$\mathbf{AQ} = \mathbf{Q} \tag{3.65}$$

$$\mathbf{pA} = \mathbf{p} \tag{3.66}$$

By assuming an equality between the different elements of the system, whereas previously stating an identity, the hypothesis of constant returns to scale is explicitly stated. If the goal is to define the quantity that we must produce in order to satisfy the demand of the final sector, represented by the last column of matrix $\mathbf{A}$, we must assume constant returns. However, if the goal is to find the prices of the present real system (like Sraffa's goal) there is no need to assume this hypothesis.

The last row of matrix $\mathbf{A}$ corresponds to the net output of each industry: it thus expresses the distribution of the surplus between the industries. As the surplus remains inside the system, the model is called a closed Leontief model. We can read this last line as the different added values created by each corresponding industry: this added value includes wages, profits and rents. This explains why the system is in a stationary state: there is no net investment, the surplus is entirely consumed by the system in order to reproduce the quantity of goods at each period.

In order to get positive solutions, determinant of matrix $\mathbf{I} - \mathbf{A}$ must equal zero, i.e. at least one column must be linearly dependent from the others. Actually, this equals to impose that demand (column n) equals the production of the system (the $n - 1$ columns). This can be interpreted as the full employment condition of Keynes: global volume of final demand must be equal to the production capacity of the system, if we want to ensure full employment (Pasinetti, 1975, p. 60). By stating the amount of available labor Q_n is an exogenous data, system 3.65 is determined. However system 3.66 remains undetermined: we can only find the relative prices once the price of one good is arbitrarily fixed. Price is then a ratio which expresses the exchange relation between the physical units of two goods (Pasinetti, 1975, p. 61).

3.4.2 The open Leontief model

In order to separate the question of production from the question of demand, the last column of matrix $\mathbf{A}$ can be deleted. Matrix $\mathbf{A}$ is now of dimension $n - 1$, $n - 1$ and we add to it a row vector $\mathbf{a}_n$ of direct labor coefficients a_{ni};

vector $\mathbf{Q}$ is also reduced to dimension $n-1$. We can then define the open Leontief model:

$$(\mathbf{I}-\mathbf{A})\,\mathbf{Q}=\mathbf{Y} \tag{3.67}$$

$$\mathbf{a}_n\mathbf{Q}=L \tag{3.68}$$

$$\mathbf{p}\,(\mathbf{I}-\mathbf{A})=\mathbf{V} \tag{3.69}$$

With $\mathbf{Y}$ the column vector of non-negative surplus (considered as given and expressing demand of consumption goods and net investments), L the amount of labor which is required by the system (it is an unknown), and $\mathbf{V}$ the column vector of added values created by the system (considered as given). The unique solution for the physical system 3.67 is the following one:

$$\mathbf{Q}=(\mathbf{I}-\mathbf{A})^{-1}\,\mathbf{Y} \tag{3.70}$$

With the condition that:

$$L\leq Q_n \tag{3.71}$$

The necessary and sufficient condition to get only positive coefficients in the solution vector is that the maximal eigenvalue of $\mathbf{A}$ must be lower than unity: $1>\lambda_m$. This means that the system must at least be in a reproduction state, and if not, must generate a net surplus, in order to have a positive solution. Coefficients α_{ij} of the inverse matrix $(\mathbf{I}-\mathbf{A})^{-1}$ represent the physical quantities of good i directly and indirectly required in order to produce one physical unit of good j.

For the price system 3.69, the solution is the following one, with the same conditions about the positivity of the solution:

$$\mathbf{p}=\mathbf{V}\,(\mathbf{I}-\mathbf{A})^{-1} \tag{3.72}$$

Thus we see that the goal of Leontief model is to highlight the relations between the industries, and to investigate, with the assumption of constant returns to scale, impacts (in terms of quantities or added value) created by a change in demand or by a change in production. Given that the added values are given, no question about a theory of value can arise.

3.4.3 Von Neumann

Von Neumann (1946) presents a model showing that it exists a scheme of production where the economic growth rate is equal to the uniform rate of interest (equivalent to the rate of profits). His model has the following characteristics:

- "Goods are produced not only from 'natural factors of production', but in the first place from each other. These processes of production may be circular" (Von Neumann, 1946).

- [The model of production] "can describe the special case where good G_j can be produced only jointly with certain others, viz. its permanent joint products" (Von Neumann, 1946) – joint production is allowed.

- "Wear and tear of capital goods are to be described by introducing different stages of wear as different goods, using a separate P_i [process] for each of these" (Von Neumann, 1946) – fixed capital is represented in the model.

- "If there is excess production of G_j, G_j becomes a free good and its price $y_j = 0$" (Von Neumann, 1946) – costly disposal is not introduced. There are no scarce resources (all natural resources are "free goods") and there is "free disposal" (if there is excess production, the price is just set to zero).

Von Neumann assumes that there are more techniques of production (i.e. processes) than goods to produce. The goal of the model is to define the more profitable techniques of production, so that each commodity is produced by only one process. The wage is defined in an exogenous way and distributed at the beginning of the period of production. The surplus is totally reinvested, and the model allows only one rate of growth and one rate of interest (equal to the rate of profit). If there is excess production, the price of the good becomes equal to zero, and if one process is not as profitable as the uniform rate of profit, it is not operated. Von Neumann demonstrates that a solution for the level of activities and the prices can always be found and that, in this solution, the rate of growth must be equal to the rate of interest.

His system can be written with $\mathbf{A}$ and $\mathbf{B}$ the matrices of inputs and outputs of each process - demand for consumption goods ("necessities of life") is expressed by a row in matrix $\mathbf{A}$ -, $\mathbf{q}$ the column vector of activities, $\mathbf{p}$ the column vector of prices (those two vectors do not have the same dimension as there are more processes than resources), g the rate of growth and r the rate of interest (or rate of profits):[23]

$$\mathbf{q}^T\mathbf{B} \geq (1+g)\,\mathbf{q}^T\mathbf{A} \tag{3.73}$$

$$\mathbf{Bp} \geq (1+r)\,\mathbf{Ap} \tag{3.74}$$

$$\mathbf{q}^T\left[\mathbf{B} - (1+g)\,\mathbf{A}\right]\mathbf{p} = 0 \tag{3.75}$$

$$\mathbf{q}^T\left[\mathbf{B} - (1+r)\,\mathbf{A}\right]\mathbf{p} = 0 \tag{3.76}$$

With $\mathbf{q}$ and $\mathbf{p}$ superior or equal to $\mathbf{0}$. Relation 3.73 states that the inputs are equal to the preceding period outputs. Relation 3.74 states that there cannot be any profits higher than the uniform one. Relation 3.75 states that if there

[23]This presentation owes much to Kurz and Salvadori (1993).

is excess production, the price of the good equals zero (rule of "free disposal"). Finally relation 3.76 states that if one process is not profitable enough, it will not be operated. Von Neumann furthermore assumes that $\mathbf{A} + \mathbf{B} > 0$, which means that all processes use at least one input or produce at least one output.

Kurz and Salvadori (1993) argue that Von Neumann's model is closed to the classical tradition, because there is no initial endowment, the rate of profit is uniform (he is considering a competitive economy), and preferences of consumers are given in physical terms. The difference with Sraffa is that Von Neumann's system is supposed to operate at equilibrium (one rate of profit), where Sraffa never assumes such equilibrium. Both theories find the same result in single production, with the same number of processes than resources (Kurz and Salvadori, 1993), but Sraffa's theory could also describe a system with several different processes operating the production of the same good (a rent would appear, whereas in Von Neumann, only the more profitable would operate), and could describe a system with different rate of profits, one for the basic processes, and several different rates for the non-basic processes.

Furthermore, Sraffa does not say that scarcity is not present in his model and that there is no costly disposal: on the first point, he says that if scarcity would happen, then several processes will be needed to produce the same good (Sraffa, 1960, Chapter XI), and about the second point he does not say anything. And finally the model of Von Neumann allows only for one uniform rate of growth, meaning that structural changes of the economy are not possible: it is a case of proportional dynamics, where the system grows steadily, without any change in the proportions. Even if it is hard to know the conceptions of Sraffa on the dynamics of economic systems (Pasinetti, 2012b), proportional dynamics seem to be irrelevant when we look at empirical data,[24] and Sraffa's interests seems to be directed into the observation of real economic systems and into the conception of an objective representation of these real systems.

3.4.4 On the neoclassical theory of general equilibrium

3.4.4.1 Generalities

The neoclassical answer to the neo-Ricardian criticisms was first to abandon for a while the aggregated function of production, and to develop general equilibrium models. These are exchange models, with a quantity of resources which is given initially. The exchanges can be made inter-temporal through the addition of a time index for each exchanged quantity (Arrow and Debreu, 1954; Arrow and Hahn, 1971). We have then a system of rent-prices for all resources, present and future ones, depending on the individual preferences (expressed

[24] Pasinetti (1993, p. 3-8), looking at the evolution of employment in three different sectors in several countries, developed or not, shows that the structure of the economy evolves in the course of time (with always more employment and value production, in terms of GDP share, in services, and always less in agriculture and industry). These are systematic and irreversible changes, clearly visible in a 20 year period, and they go against proportional dynamics approaches (whether in multi-sectoral or aggregated models, i.e. when the economy produces only one good).

by utility functions) and the initial distribution of resources. In this system of price, we can define a rate of interest, specific for each resource and which can be assimilated to a rate of profit, regarding the evolution over time of the different prices. Wage is in this kind of model the price of the labor resource. Thus there is no distribution problem: we are only concerned with the search for the prices which will allocate optimally the resources.

Let us say that we have a set of goods and capitals (share of profits for instance) allocated to a set of agents, a set of preferences, and a set of functions of production (these are the parameters of the general equilibrium models, Guerrien, 1989). There exists at least one set of prices that allows the exchanges so that we observe maximisation of utility and maximisation of profits, and that, for each good, the demand equals the supply (this is the definition of the general "walrasian" equilibrium, Walras, 1874; Arrow and Debreu, 1954). But in order to ensure that at least one set of prices exists, we must assume the following hypotheses:

1. There is a complete system of markets, i.e. for all present and future goods;
2. There is perfect competition, i.e. all agents are price-takers, they take decisions only by looking at prices and they are perfectly informed about these prices (and no coalition of agents able to influence these prices is allowed);
3. There are no increasing returns to scale, no increasing marginal productivities, and no fixed costs.
4. There is no obligation to make exchanges, i.e. all agents can survive without making exchanges.

Even with these assumptions, there is the possibility that several equilibrium exist: actually, very restrictive hypotheses need to be added in order to ensure the uniqueness of the equilibrium (such as the hypothesis of diagonal dominance). The Sonnenschein-Mantel-Debreu theorem (Sonnenschein, 1973; Mantel, 1974; Debreu, 1974) furthermore shows that if there are several equilibria, no criteria can assess which one is the optimal one, and no rule can be assessed concerning the change of prices, revenue and profits from one equilibrium to the other (for instance there can be no a priori connection between scarcity and value - or else there is again the need to add very restrictive hypotheses, such as the hypothesis of binary changes).

This theorem also shows that nothing ensures that the system will converge to equilibrium: to ensure this, either we need to assume that an auctioneer sets a unique price for each good, informs the agents about the prices, but does not allow them to make exchanges until he finds the equilibrium prices, or we need to abandoned the hypothesis of perfect competition. In the first case, we need again further restrictive hypotheses in order to ensure the stability of the process. In the latter, agents set the prices, based on their ideas about the market and their competitors: there is again no insurance that a "walrasian" equilibrium is reached (an equilibrium could be reached where no exchanges can be made, but with some demand and some offers still not satisfied).

If one walrasian equilibrium is found, its optimality is ensured through the Pareto criterion: at equilibrium, the utility of all agents is optimized, depending on the conditions of production and on the initial distribution (which could actually be very unfair), and if the preferences are convex (if the marginal rate of substitution is decreasing for all goods and all agents) then, for all Pareto optimal distribution, there exists a set of equilibrium prices. However, this criteria of optimality is based on the belief that all agents are rational (they can order the set of goods following one preference criteria, without knowing their prices, and this preference relation is transitive) and on the assumption that there are no externalities (Guerrien, 1989).

What is at the heart of the neoclassical methodology is to start from the definition of the agents, and then to observe their interactions. The goal is then to deduce some general laws that can be applied to the society: this is a reductionist approach, following a individualist methodology. Neoclassical economists tried to described a perfect competition economy, hoping that they could show that free markets lead to the best allocation of initial resources. But in order to do this, they need first to endogenize agents' preferences, and then to assume far-from-reality hypotheses. The starting point (subjective preferences that could be measured and taken as parameters) is therefore disputable and the results (uniqueness and stability of the optimal equilibrium) are disappointing.

The neoclassical theory of distribution assumes that, when prices are given so that an equilibrium, depending on initial distribution and preferences, can be reached, the quantities (of goods produced and labor employed) are fixed so that their marginal productivities equals their prices. But of course, in the real world, with real competition, prices are not given in highly centralised way. And a mistake done by several neoclassical authors is to think that, given the quantities of goods produced and labor employed, in a competitive market, prices are set equal to marginal productivities (this is wrong since prices are set and influence the quantities in order to get this result). This mistake explains why profits are often assumed to be null at equilibrium where, actually, they can be positive if returns to scale in production are decreasing.[25]

The approach of Sraffa is less subjective (no preferences are taken into account), and appears to be more general that the neoclassical approach (there is no need to assume perfect competition, for instance).[26] But of course Sraffa's goal was not to prove that free markets are optimal: Sraffa only wanted to show

[25]The problem being that, if profits are positive, they are not related with any factor of production (they do not remunerate any factor of production). Thus the neoclassical hypothesis that the fairest distribution should be according to the marginal productivity of each factor (like in the aggregated function of production of the Cobb-Douglas type) does not apply to profits. That explains why some neoclassical economists prefer to assume that, in the long run, profits are null (Guerrien, 2012).

[26]Of course this is disputed by neoclassical economists. Guerrien (1989) denies this because he thinks that Sraffa's critique of neoclassical theory is based on steady-state assump-

that prices can be deduced from the conditions of production and distribution, in a static way. Sraffa then showed that economic results such as the rate of profits, the prices, the wage, can be deduced from another starting point than the neoclassical individualist one, and that this methodology may be more relevant, because based only on past production and distribution (and not on present and future preferences and production).

3.4.4.2 An example

We can develop Wicksell model through the question of the choice of techniques, by applying linear programming methods. Consider the column vector $\bar{\mathbf{q}}$ containing the $n-1$ quantities of commodities $\bar{q}_i$ and the quantity of available labor $\bar{q}_n$, all these quantities being given at the beginning of the period of production (this presentation is from Pasinetti, 1975, p. 187). Let the rectangular matrix of technical coefficients$\tilde{\mathbf{A}}$ have n rows and at least $n-1$ columns representing the different available methods to produce the $n-1$ commodities (there could be an infinity of methods, here we will assume that there are $(n-1)\times\omega$ techniques). The system can then be written in this way:

Maximise:

$$\bar{\mathbf{p}}\mathbf{x} \tag{3.77}$$

Knowing that:

$$\tilde{\mathbf{A}}\mathbf{x} \leq \bar{\mathbf{q}} \tag{3.78}$$

$$\mathbf{x} \geq \mathbf{0} \tag{3.79}$$

With $\bar{\mathbf{p}}$ the line vector of the given prices, positive or equal to zero, of the $(n-1)\times\omega$ produced commodities, and $\mathbf{x}$ the column vector of the $(n-1)\times\omega$ levels of activity of the different methods of production. The objective function is to maximise the revenue by using the methods that will allow the highest production of the commodities which have the highest prices. We can note that in the optimal solution $\mathbf{x}^*$, a good can be produced by several different techniques.

This problem can be also expressed by the dual minimisation program:

Minimise:

$$\mathbf{r}\bar{\mathbf{q}} \tag{3.80}$$

Knowing that:

$$\mathbf{r}\tilde{\mathbf{A}} \geq \bar{\mathbf{p}} \tag{3.81}$$

tions - one unique rate of interest, which is due to one unique rate of growth for all processes. And Samuelson (2008) asserts that Sraffa's system is a system with constant return to scale and perfect competition.

$$\mathbf{r} \geq \mathbf{0} \tag{3.82}$$

With $\mathbf{r}$ the line vector of *rent-prices* allocated to the n factors of production (the $n-1$ commodities and labor). Here the goal is to minimise the cost of use of the given resources, by using the techniques that will minimise the quantities used, especially for the goods which have the highest prices.

The first system tries to maximize the value of the outputs, the second to minimise the cost of the inputs. Both are linked through their optimal solutions $\mathbf{x}^*$and $\mathbf{r}^*$:

$$\mathbf{r}^*\bar{\mathbf{q}} = \mathbf{r}^*\tilde{\mathbf{A}}\mathbf{x}^* = \bar{\mathbf{p}}\mathbf{x}^* \tag{3.83}$$

Generally, non used techniques (with a zero x_i^*) are the ones using too costly inputs ($\mathbf{r}\tilde{\mathbf{A}} > \bar{\mathbf{p}}$), i.e. that are not efficient in the use of the scarce available resources. On the other hand, rent-prices are positive when the corresponding commodities are entirely used: $\tilde{\mathbf{A}}\mathbf{x} = \bar{\mathbf{q}}$. Thus the rent is only existing when demand (expressed by prices $\bar{\mathbf{p}}$) about one commodity is higher than the supply (expressed by the quantities $\bar{\mathbf{q}}$, initially given at the beginning): rent-price can be seen as a scarcity index and thus can be related to the definition of price in the marginalist theory. And we can find also the relation between revenue and marginal productivity by partially differentiating the objective function $\bar{\mathbf{p}}\mathbf{x}$ of the first program vis-à-vis each physical quantity of initial resources: these partial derivatives will be equal, or closed to the corresponding rent-prices. If we generalise this result by denoting the derivative which is approaching the solution from the left side of r_i, $[\delta(\bar{\mathbf{p}}\mathbf{x})/\delta q_i]^-$, and the derivative which is approaching from the right side $[\delta(\bar{\mathbf{p}}\mathbf{x})/\delta q_i]^+$, we can generalise Wicksell solution 3.29 for all factors of production:

$$\left[\frac{\delta(\bar{\mathbf{p}}\mathbf{x})}{\delta q_i}\right]^- \geq r_i^* \geq \left[\frac{\delta(\bar{\mathbf{p}}\mathbf{x})}{\delta q_i}\right]^+ \tag{3.84}$$

In a situation of free competition, and with the hypothesis that all factors can substitute each others, rent-prices will then express the scarcity of the corresponding factors of production and will reveal the profitability of the last physical unit of this factor used in the process of production (as a result the revenue will be optimally distributed).

In the model above, demand is represented by the vector $\bar{\mathbf{p}}$ of prices: but where does this vector come from? We can imagine that these prices reflect the preferences of one agent. In this case the neoclassical theory of value, linking scarcity and value, is still valid. However, what does happen when a second agent is introduced, with a different vector of prices? Here arises the problem of the aggregation of individual choices. The theorem of Sonnenschein-Mantel-Debreu (Sonnenschein, 1973; Mantel, 1974; Debreu, 1974; Guerrien, 1992) proves that, as soon as several agents are introduced, the relation between scarcity and value disappears. More precisely, one of the consequence of this theorem is that if the quantity of one resource is increased, all things being equal, the price of this good may not relatively decrease.[27] Even if we do not aggregate the means of production into the capital factor, the neoclassical theory of value is not therefore satisfactory. One of the principles supporting the neoclassical theory of exchange has been proved wrong, first during the Cambridge controversy, and then with this theorem.

[27]"Si on considère les équilibres de deux économies qui ne différent que par la quantité disponible de l'un des biens intervenant dans les dotations initiales, il se peut fort bien que le prix relatif (par rapport au numéraire) de ce bien augmente alors que sa quantité disponible augmente également (on ne peut alors identifier valeur et 'rareté')" (Guerrien, 1992).

Chapter 4

Neo-Ricardian Economics and the environment

4.1 Introduction

In one draft note, Sraffa states that:

> "the difference between the 'Physical real costs' and the Ricardo–Marxian theory of 'labor costs' is that the first does, and the latter does not, include in them the natural resources that are used up in the course of production (such as coal, iron, exhaustion of land) [Air, water, etc. are not used up: as there is an unlimited supply, no subtraction can be made from ∞]. This is fundamental because it does away with 'human energy' and such metaphysical things. ... But how are we going to replace these natural things? There are three cases: a) they can be reproduced by labor (land properties, with manures etc.); b) they can be substituted by labor (coal by hydroelectric plant: or by spending in research and discovery of new sources and new methods of economising); c) they cannot be either reproduced nor substituted - and in this case they cannot find a place in a theory of continuous production and consumption: they are dynamical facts, i.e. a stock that is being gradually exhausted and cannot be renewed, and must ultimately lead to destruction of the society. But this case does not satisfy our conditions of a society that just manages to keep continuously alive" (Sraffa's Unpublished Papers and Correspondence, Trinity College Library, Cambridge, UK, as catalogued by Jonathan Smith, D3:12:42: 33, dated 25 March 1946; Sraffa's emphasis, quoted in Kurz and Salvadori, 2000).

Thus Sraffa states that his theory, the "Physical real costs" theory, is taking into account the natural resources. However, I will argue that this is not true: my position is that Sraffa is not dealing with natural resources, but with commodities produced by industries and exchanged in the market. Those resources that are not produced by industries or which are not exchanged in the market (for instance, wastes) are not encompassed by his model, and cannot receive a price.

And we have a confirmation of this when, in chapter XI of his book, Sraffa explicitly introduces natural resources:

> "natural resources which are used in production, such as land and mineral deposits, and which being in short supply enable their owners to obtain a rent, can be said to occupy among means of production a position equivalent to that of 'non-basics' among products. Being employed in production, but not themselves produced, they are the converse of commodities which, although produced, are not used in production" (Sraffa, 1960, § 85).

In this chapter, we will see how Sraffa deals with natural resources in his book, through the problematic of the rent, in section 4.2 (after a short introduction on the use of the rent in Quesnay and Ricardo's theories). We will then see how the neo-Ricardians manage to introduce these resources in their models and how they deal with general environmental problems. First we will see the case of exhaustible resources in section 4.3 and then we will study the introduction of waste, the problem of the control of pollution and the exploitation of renewable resources in section 4.4.

4.2 Rent

4.2.1 Quesnay

Quesnay is one of the firsts to introduce the concept of rent into an economic model: his famous "Tableau Economique" is presented in Versailles in 1758 and is reproduced in table 4.1. The society is divided into three classes: the productive, the infertile and the aristocratic. Land is the only factor of production which enables to produce a surplus, i.e. to produce more goods than needed by its exploitation. The productive class works in agriculture and mines (it is thus exploiting the land), produces food products and raw materials and consumes food products. The infertile class is not producing any surplus, it transforms raw materials into manufactured goods and consumes food products. The aristocratic class owns the money, receives the rent from the use of the land, and consumes food products and manufactured goods. Once the period of production is ended, the money is given to the infertile class in exchange for the manufactured goods and to the productive class in exchange for the food products. The infertile class will use the money to pay for the raw materials and the food products. The productive class will then have all the money and will transfer everything to the aristocratic class to pay the rent on the use of the land.

Table 4.1: The Tableau Economique as an input-output table (numbers represent billions) (Pasinetti, 1975)

Entries		*Outputs*			
		Productive class	Infertile class	Aristocratic class	General sum
Productive class	- food products	1	1	1	5
	- raw materials	1	1	-	
Infertile class		1	-	1	2
Aristocratic class		2	-	-	(2)
General sum		5	2	(2)	7

Represented in the form of table 4.1, the Tableau Economique is an example of a closed Leontief model (Leontief, 1941): the inter-industry sector is represented by the exchanges between the productive and the infertile classes, and the final sector is represented by the aristocratic class. The surplus of the system goes entirely in the hands of the aristocracy: it is represented by the goods owned by the aristocracy at the end of the period of production (third column) and by the added value created and returned to the aristocracy in the form of rents for the use of land at the end of the period of production (fourth row).

Thus the added value comes from the use of the land: this theory of value will soon be replaced by the labor theory of value developed by classical authors (Smith, Ricardo). But this vision of the land as the true source of economic wealth will be taken over in a slightly modified version in the 1970s by the tenants of the new "energetics" dogma (Georgescu-Roegen, 1979): these researchers think that energy, instead of land, is the real source of added value and the only limiting input of the system of production - everything can be produced providing that there is enough energy (for a comparison between this vision and Quesnay's theory, see Burkett, 2003).

4.2.2 Ricardo, extensive and intensive rent

At the beginning of the XIX$^{\text{th}}$ century, Ricardo (1817) builds a consistent economic theory, including at the same time a theory of value and a theory of distribution. He develops also his conception of the differential rent: either extensive (when various qualities of one resource are used at the same time in a system of production), or intensive (when various techniques producing the same good are used at the same time). The rent on one process represents the difference between the profitability of this process and the profitability of the least profitable process producing the same good (also called the marginal technique, which does not generate a rent). The price of the good produced by the different methods is determined according to the marginal technique.

This conception of the rent will then be taken over by the neo-Ricardian school.

However, Ricardo also assumes some contestable hypotheses: the "law of diminishing returns" (resources of better qualities are used first, as well as the more profitable techniques) and the absence of technical progress in agriculture, where the theory of differential rent applies. These hypotheses will later, consciously or not, be taken over by marginalist authors, applying intensive rents to all sectors and to all factors of production (see for instance Clark, 1899; Wicksell, 1934).

This abusive expansion of the concept leads to important consequences (Pasinetti, 1999, 2000): on one hand the study of technical progress is abandoned, and on the other hand all factors of production are considered to be scarce, just like the factor *land*. As a consequence, a realistic theory of distribution and production is abandoned, following the introduction of the neoclassical aggregated function of production (usually of Cobb-Douglas type, Cobb and Douglas, 1928), which is criticized on both theoretical (Robinson, 1954; Felipe and McCombie, 2013) and empirical (Sylos Labini, 1995) levels.

Sraffa has built a proposal able to contradict the neoclassical appropriation of Ricardo, but he nevertheless introduces rent into his theory.

4.2.3 Rent and Sraffa

A rent arises as soon as two different processes, with different profitabilities, produce the same good.[1] But in Sraffa's theory, even if there is no equilibrium in terms of demand and supply,[2] it is assumed that the choice of processes is optimal: only the most profitable ones are represented. This allows Sraffa to avoid investigating reasons why two different techniques with different profitabilities are used at the same period of production: this would require a dynamic analysis of the development of new methods, of the influence of monopolies and dominant positions and into political considerations (for instance old-fashioned techniques may be protected by the government in order to save jobs, or new techniques may be protected so that they can grow and be more competitive). This is why the only possible rents to be found in Sraffa's equations are related to absolute scarcity,[3] i.e. related to the presence of a natural resource which cannot be produced.[4]

In this case, if the demand for natural resources is high enough (so that even if the natural resource under consideration is renewable, it starts to be depleted), new methods of production have to be introduced in order to satisfy the demand. These new methods may be more or less profitable than the already existing ones, and may or may not use the natural resource. If they are more profitable, Sraffa assumes that they will directly replace the old methods. If they are less profitable, there is the possibility that both new and old methods

[1]This is due to the hypothesis that each commodity can only receive one unique price. This assumption could of course be discussed: when a more profitable technique is introduced, usually the price of the commodity produced by this new technique is lower than the price of the commodity produced by the older technique, in order to attract new consumers.

[2]Supply may differ from the effective demand as prices are not completely equilibrium prices: "this is not proposed as a complete system of equilibrium" (D3/12/46:20, dated 2 April 1957, quoted in Sinha, 2013).

[3]This is not exactly true, as Sraffa also talks about quasi-rents: these rents are earned by owners of machines which are still used even if their allowed life-span is passed. This capital does not appear as a joint-product, but only as an input with no price: the surplus earned because of this non-priced input is the quasi-rent (Sraffa, 1960, § 91).

[4]But then labor is also not produced: could it be that labor becomes a scarce resource? If labor were scarce, it would mean that one process producing one commodity already produced should be added (otherwise it is not possible to know that labor is scarce): then, depending on the profitability of this process, the rent on labor could be calculated (see Abraham-Frois and Berrebi, 1979 on this point). However, first this could lead to marginal thinking where all factors of production are scarce (see Lipietz, 1979 on this point). Secondly, Sraffa actually briefly considers, in the beginning of his book, labor as a produced commodity in the "production for subsistence" case. And even if later he chooses to consider wage as an entirely exogenous variable, thus also avoiding such complications, he still thinks that the "necessaries of production" will influence production in the way that labor could always be produced: "we have up to this point regarded wage as consisting of the necessary subsistence of the workers and thus entering the system on the same footing as the fuel for the engines or the feed for the cattle. ... We shall, nevertheless, ... follow the usual practice of treating the whole of the wage as variable. ... Necessaries [of consumption] however are essentially basic and if they are prevented from exerting their influence on prices and profits under that label, they must do so in devious ways (e.g. by setting a limit below which the wage cannot fall; a limit which would itself fall with any improvements in the methods of production of necessaries, carrying with it a rise in the rate of profits and a change in the prices of other products)" (Sraffa, 1960, § 8)..

operate at the same time. This expresses the fact that the natural resource is scarce, for if it were not scarce, only the most profitable technique would be used: "while the scarcity of land provides the background from which rent arises, the only evidence of this scarcity to be found in the process of production is the duality of methods: if there were no scarcity, only one method, the cheapest, would be used on the land and there could be no rent" Sraffa, 1960, § 88). Sraffa considers only the introduction of less profitable methods using the same natural resource to produce the same good: in this case, they have to be more productive per unit of natural resource than old methods in order to satisfy the demand (an example of the introduction of a less profitable technique not using the natural resource to produce the same good can be found in Erreygers, 2014).

If two methods produce the same good, a rent will then arise. This rent can be seized by the owner of the more profitable method, or by the owner of the natural resource.[5] Sraffa considers that the owner of the natural resource receives the rent: the rent is then paid in a proportional manner as compared to the use of the natural resource. As natural resources are not produced, they cannot appear in the standard system: they are equivalent to non basic goods in this respect. Thus rents are calculated after the calculation of the rate of profit and the prices of basic commodities.[6] Sraffa then makes a difference between two types of rents. The first occurs when the natural resource is of different qualities (e.g. in the case of land, lands could have different fertilities). We can call this the extensive rent. The second occurs when the natural resource is homogeneous. We can call this the intensive rent (both terms are not used by Sraffa, who makes only reference to extensive and intensive diminishing returns).

In the case of extensive rent, when different qualities of one natural resource are used, the least profitable quality does not pay any rent. The technique using the no-rent quality is used in order to calculate the price of production (so the natural resource does not appear in the standard system) and after that, the price of production is used to deduce the rents. As it is not possible to know which quality is the least profitable before calculating the prices, each method has to be tested, the least profitable being the one which allows to deduce only positive rents. Sraffa takes the example of corn production (coefficient k) with n land of different qualities (Sraffa, 1960, § 86). The n different methods of production are presented in this way:

$$\begin{array}{c}
\left(a_{k_1,1}p_1 + a_{k_1,2}p_2 + \ldots + a_{k_1,k}p_k + \ldots + a_{k_1,m}p_m\right)(1+\pi) + l_{k_1}w + \Lambda_1\rho_1 = b_{k_1}p_k \\
\left(a_{k_2,1}p_1 + a_{k_2,2}p_2 + \ldots + a_{k_2,k}p_k + \ldots + a_{k_2,m}p_m\right)(1+\pi) + l_{k_2}w + \Lambda_2\rho_2 = b_{k_2}p_k \\
\vdots \\
\left(a_{k_n,1}p_1 + a_{k_n,2}p_2 + \ldots + a_{k_n,k}p_k + \ldots + a_{k_n,m}p_m\right)(1+\pi) + l_{k_n}w + \Lambda_n\rho_n = b_{k_n}p_k
\end{array} \tag{4.1}$$

[5] See section 4.2.5 for an example exploring both possibilities.

[6] And, like with non-basic goods, taxation on rents will not influence the prices of basic goods and the rate of profit: it will only influence the revenue of the rentier.

With Λ_i the given quantity of land of quality i, ρ_i the rent on this land and knowing that $\prod_{i=1}^{n} \rho_i = 0$, because the least profitable land pays no rent.

If the land is homogeneous, intensive rent will arise. Sraffa says that this rent is uniform and is proportional to the amount of natural resource used in production.[7] The two different techniques can be represented in this way, with r the uniform intensive rent (this representation is from Kurz, 1978 - Sraffa did not propose any algebraic formulation for the calculation of the intensive rent):

$$\begin{array}{c} \mathbf{a}_1\mathbf{p}\,(1+\pi) + l_1 w + \Lambda_1 r = \mathbf{b}_1\mathbf{p} \\ \mathbf{a}_2\mathbf{p}\,(1+\pi) + l_2 w + \Lambda_2 r = \mathbf{b}_2\mathbf{p} \end{array} \tag{4.2}$$

The standard system is built so that the ratio between input and surplus of the standard system for each commodity is uniform. With q_i the multiplier of process i in the standard system, we must have:

$$\begin{array}{c} (q_1\mathbf{a}_1 + q_2\mathbf{a}_2)\,(1+R) = q_1 + q_2 \\ q_1\Lambda_1 + q_2\Lambda_2 = 0 \end{array} \tag{4.3}$$

Both multipliers will have opposite signs, so the natural resource can be eliminated.[8] We can then calculate the rent, when the prices of basic goods are known:

$$r = \frac{\mathbf{b}_1\mathbf{p}}{\Lambda_1}(1 - \frac{k_1}{\mathbf{b}_1\mathbf{p}}) = \frac{\mathbf{b}_2\mathbf{p}}{\Lambda_2}(1 - \frac{k_2}{\mathbf{b}_1\mathbf{p}}) \tag{4.4}$$

With $k_i\,(w) = \mathbf{a}_i\mathbf{p}\,(1+\pi) + l_i w$ the cost of inputs of method i. Thus the method producing more outputs per unit of natural resource must have a bigger cost of inputs per unit of output than the second method, otherwise the rent would be negative: if $\frac{\mathbf{b}_2}{\Lambda_2} > \frac{\mathbf{b}_1}{\Lambda_1}$, then it must be that $\frac{k_2}{\mathbf{b}_2} > \frac{k_1}{\mathbf{b}_1}$ (Sraffa, 1960, § 87, Kurz, 1978).

The first method being the more profitable, if there were no rent, it would be the only one to be used. As demand is more important than what method 1 can produce, technique 2 is also used: it is more productive (otherwise demand could not be satisfied) but less profitable (otherwise it would replace entirely method 1). In order to calculate the prices, a rent has then to be introduced: as it is paid per unit of natural resource used, it impacts both methods in the same way (they become equally profitable).

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[7] Bidard (2013) underlines that, in Ricardo, the intensive rent is not uniform: the least profitable method also pays no rent, just as the extensive rent. Ricardo's logic is that the intensive rent arises because the process is intensified on all the homogeneous land: then, considering the various qualities of the land, an extensive rent and an intensive rent will arise. This is not the same logic as in Sraffa, as the two methods operate on different parts of the homogeneous land.

[8] If rent is paid before production, we get the same system4.3: thus I disagree with Lipietz (1979) who thinks that both possibilities lead to different results. The important thing is that the natural resource is eliminated during the construction of the standard system - no matter if rent is a distribution variable or a factor of production: as the standard system considers only basic goods, the natural resource must disappear, as well as labor and non-basic goods.

Both rent, intensive and extensive, can coexist at the same time for a given natural resource and several commodities can use the same scarce natural resource for their production, leading to several different rents (Sraffa, 1960, § 89).

4.2.4 Sraffian rent and dynamics

4.2.4.1 Dynamics and causal relations

Intensive rent is seen as a dynamic phenomenon for Sraffa. He thinks that system 4.2 allows a continuous increase in the production of output: if the demand is increasing, method 2 will be more and more used and thus rent will increase, until method 1 is abandoned. At this moment, there will be a possibility that a new technique more productive but less profitable appears, allowing again for a continuous increase of production (Sraffa, 1960, § 88). We must note that even if the increase of production is continuous, the level of the rent is discontinuous: each time a new technique appears, the level of the rent may increase or decrease suddenly. In all the § 88 paragraph, Sraffa has a dynamic reasoning: he explains why, in a dynamic way, intensive rent appears and how the system can evolve to answer to scarcity.

Sinha (2009) writes about the reluctance of Sraffa to take into consideration causal relations, or dynamics, into his theory:

> "in a note of 1928 [Sraffa] characterized the theory of value as a 'geometrical theory' and its 'object' as 'a photograph of a market place' where 'no visible movement takes place' (PSP D3/12/7, 1928), implying that his propositions do not rest on causal relations, as causal relations can be inferred only when one takes into account time and change. The theme again crops up in another note of 1929 where he tries to distinguish between extensive and intensive rents on the basis of the former being a 'geometrical' or 'timeless' representation whereas the latter requiring 'change, or movement: that is to say, we require time' (PSP D3/12/13:23)".[9]

When Sinha talks about causality, he means mechanical causality, i.e. a succession of related events, implying a temporal rather than a logical relation. Intensive rent requires time (i.e. causal explanation) to explain why two methods are jointly used on a homogeneous natural resource, whereas the fact that different qualities of a natural resource exist explains by itself, at a logical level, the different profitabilities, which could lead to the appearance of extensive rents.

Actually, if Sraffa's system is a real photograph of a market place, it is to be expected that several processes producing the same commodity but with different profitabilities will be the rule more than the exception, even if this commodity does not require any natural resources as input. A rule has then

[9]The notes comes from the Wren library, Trinity College, Cambridge.

to be decided on the question of who is earning - or who is paying - the rent: this question can only be answered by looking at dynamic causes (it depends on institutions, power relationships, etc.). Sraffa apparently did not want to introduce such causal explanations in his simple model. This is why he talks only about the rent on natural resources, and in this case, he states that the rent is earned by the owner of the natural resource.[10]

4.2.4.2 The problem of external rent

A good example of the fact that the real market may be full of rents is the introduction of a new kind of rent by Saucier (1981): the external intensive rent. This rent arises when an increase of demand does not lead to the apparition of a new technique in the sector exploiting the scarce natural resource, but in a sector using as input the commodity produced by the sector exploiting the natural resource. For instance, let us look at a system producing corn and coal as two basic goods. The corn sector uses land, which is fully cultivated. Now, the demand for coal increases; as the land is fully cultivated, the production of corn cannot increase. Thus there are two possibilities: either a new method arises in the corn sector, and if this method is more productive but less profitable, intensive rent will arise; or a new method arises in the coal sector. If the latter method produces more coal per unit of corn, but is less profitable than the previous method, the old and the new method will coexist, and an external intensive rent will arise.[11]

[10]The reason why Sraffa does not want to enter into causal explanations is explained in this way by Nuno Martins (personal communication): "The reason Sraffa does not introduce politics and institutions is due to his objectivism. Not focusing on causes follows from his focus on one moment in time, in contrast to Marshall's use of differential calculus focusing on changes, and failing to overcome the problem of internal relations".

[11]This is the right causal reasoning. I disagree for instance with Bidard (2013) who asserts that the apparition of a new method in the coal sector is due to the rise of the corn price, due itself to a rise in demand: "When land is fully cultivated, the price of corn rises and the rent becomes positive". If no different method is introduced in the corn sector, the price of corn will not change (demand changes the level of the production, and thus maybe the methods of production, but does not directly influence prices) and no rent on corn will arise. Similar wrong reasoning can also be found in Salvadori (1983), who introduces the singular rent. She assumes that, if the methods of production are fixed, when the demand will increase a rent will arise on the natural resource. The level of this "singular" rent is set by assuming that there are different effective demands from the different classes of population (workers, rentiers and capitalists).

Actually this false reasoning may have its origin in Ricardo's thinking (Bidard, 2014): "Ricardo stressed that the rise of corn implies that of rents ('Corn is not high because a rent is paid, but a rent is paid because corn is high', Principles, Chapter 2)". According to Ricardo, if the demand for corn increases, the price of the corn would therefore increase and a rent could be paid. But for Sraffa, the price of corn could only increase if a new technique, less profitable, is introduced. Thus Bidard is not following a Sraffian reasoning when he states: "The incoming marginal method is the first previously non-operated method which yields the ruling rate of profit when the price of corn rises ... were the rise in the price of corn (and in other prices and rents) smaller than the critical level defined by the law, there would be no incentive to introduce a new method; were it greater, the first method we are considering would yield more than the ruling rate of profit. The level of the rise is therefore the minimum compatible with the introduction of a new method" (Bidard, 2014). The right

A good question is then: who will earn this rent? Are we keeping Sraffa's proposal that the owner of the natural resource should earn the rent? Or is it seized by the owner of the most profitable technique in the external sector? The second alternative seems more logical, as it seems difficult for the owners of the natural resources to ask the owners of the coal sector to give them the rent (see section 4.2.5 on that point).

Furthermore, an other interesting consequence of external rent is that this notion could be further expanded: as soon as there is absolute scarcity, rent can occur in the sector directly extracting the resource, but also on each sector indirectly using the resource, and all these different rents may arise during the same period of production. Thus by introducing absolute scarcity for one natural resource, if that resource is used to produce basic goods, Sraffa allows the introduction of intensive rents in all sectors.

The risk is then to fall into the neoclassical logic that asserts that the goal of the economic science has to be changed because all factors of production are scarce:

> "from a science that inquires into the nature and causes of the wealth of nations, as it was intended by Adam Smith, [the neoclassical economists] made it ... a science that deals with the use of scarce means to achieve given ends" (Pasinetti, 1999).

In order to avoid this trap, it must be reminded that Sraffa made no assumption on technological progress: new methods may be more productive and more profitable than older ones, and they may not require the same resources as inputs.

4.2.4.3 The order of fertility

The question of the order of fertility is also a dynamic one: in which order the different lands, or the different methods, will be introduced when demand will increase? It all depends on the choice of technique: when demand increases, what is the right criteria to choose the technique to introduce? Ricardo was thinking that the choice of methods depends on the productivity per acres (Bidard, 2013): the criteria of the maximum rate of profit leading to the same choice as the criteria of the maximum rate of growth (and Marx was following him on that point, Kurz, 1978). However, Sraffa shows that a change in the distribution of the surplus between profits and wages can change this order, by changing the profitability of the different techniques (a not very labor intensive method can then be more profitable if the wage increases). Thus the criteria

reasoning is: if there is an introduction of a new method, the level of the rise will be the minimum compatible with it.

We must remember that we are talking about Sraffian prices, which may differ from real market prices: if the demand is not satisfied for corn, the price of corn in the market may exceed the Sraffian price for corn, but the Sraffian theory is not able to tell the level of this increase.

of the maximum rate of profit must be predominant: profitability is more important than productivity, if the demand is satisfied.

Kurz (1978) furthermore shows that the ranking of the lands depending on their profitability does not give the same result as their ranking depending on the rent per acres. Thus a conflict can arise between landowners, seeking for the use of methods leading to high rents, and other classes of population (workers and capitalists): the choice of techniques is actually a political choice.

4.2.5 Sraffian rent and institutions

Sraffa explains the apparition of both rents (intensive and extensive) because of scarcity:

> "Natural resources which are used in production, such as land and mineral deposits, and which being in short supply enable their owners to obtain a rent, ... if there were no scarcity, only one method, the cheapest, would be used on the land and there could be no rent" (Sraffa, 1960, § 85 and § 88).

According to him, if there were no scarcity, only the most profitable technique would be used on the most profitable land. But actually other causal relations than scarcity can explain the fact that different methods produce the same good with different profitabilities: dominant position, slow propagation of a new technique, slow exploitation of a newly discovered natural resource, governmental protection, etc.

Furthermore, Lipietz (1979) warns that if scarcity could be a reason for a rent on natural resources, it is neither a sufficient reason, nor a necessary one. First, if a resource is not scarce, but entirely appropriated by an agent, this agent could establish a false scarcity, by imposing rationing on the use of the resource or by asking for a rent. This kind of rent is not introduced by Sraffa, but is introduced by Marx, who called it "absolute rent".[12] The level of this absolute rent is not dependent on the existence of two different methods for the exploitation of the natural resources, but only on power relationships (between the owner and the workers of a farm, for instance).[13]

[12] The rent in Marx can originate from (Harribey (2013), p. 82):

1. The different qualities of natural resources, as the Ricardian differential extensive rent.
2. The different intensities of production from processes producing the same good, as the Ricardian differential intensive rent.
3. The closure to competition (in the case of monopoly or quasi-monopoly), it is then called the absolute rent. This last kind of rent does not appear in Sraffa's model.

[13] In Lipietz terms: "[the level of absolute rent] dépend d'un *rapport de forces*, dans lequel interviennent bien sûr le degré d'organisation du monopole collectif des propriétaires, leur capacité (et celle des locataires) à vivre sans monnayer le droit de propriété, la capacité des différentes classes à nouer des alliances dont la rente est le gage : d'où la lutte des landlords anglais pour maintenir le monople des blés, d'où les efforts de l'OPEP, etc." (Lipietz, 1979).

Secondly, if a natural resource is scarce, the exploitation of this resource could still be free. It is only if the resource is privately appropriated that a rent can be asked on the exploitation of the resource. If two methods coexist using an homogeneous natural resource and if one method is more profitable and more productive than the other one,[14] the rent that will arise cannot be paid to the owner of the natural resource, as it would be negative. It would be seized by the most profitable process - the level of the rent is calculated in the same way as for the extensive rent: the marginal method pays no rent. If the method which is more productive is less profitable, Sraffa assumes that the rent is always seized by the owner of the natural resource. However, if there is no such owner (or if the owner does not ask for the rent), the rent is also seized by the most profitable process.

As an example of this last case, let us look at a "corn economy". Two different methods are used to produce the corn, and they both use homogeneous land. Method 1 is more profitable, but less productive, than method 2:

$$\begin{array}{lcccc} & Labor & Corn\,input\,(ton) & Land\,(acre) & Corn\,output\,(ton) \\ Method\,1 & \frac{1}{2} & 2 & 2 & 4 \\ Method\,2 & \frac{1}{2} & 2 & 1 & \frac{7}{2} \end{array} \tag{4.5}$$

Labor is normalised in such a way that total labor is equal to one, so the wage becomes equal to the value of the share of the surplus given to the workers. There are now two possibilities for the value system: either the rent is seized by the owner of the land, or it is seized by the owner of the most profitable process.

In the first case, the value system is represented in this way:

$$\begin{array}{c} (1+\pi)\,2p_c + \frac{1}{2}w + 2\rho = 4p_c \\ (1+\pi)\,2p_c + \frac{1}{2}w + \rho = \frac{7}{2}p_c \end{array} \tag{4.6}$$

With π the rate of profit, w the wage , ρ the rent and p_c the corn price. In order to construct the standard system, both methods has to be multiplied so that the land disappears and total labor remains equal to one:

$$\begin{array}{c} 2y_1 + y_2 = 0 \\ \frac{1}{2}y_1 + \frac{1}{2}y_2 = 1 \end{array} \tag{4.7}$$

With y_1 the multiplier of method 1 and y_2 the multiplier of method 2. We find that $y_1 = -2$ and $y_2 = 4$. Thus the standard system is the following:

$$(1+\pi)\,4p_c + w = 6p_c \tag{4.8}$$

The maximum rate of profit, when the wage is equal to 0, is thus $R = \frac{1}{2}$. If the numeraire is the standard commodity, we have:

[14] Their existence side by side could be explained be the course of the development of the more profitable technique: it may in future replace the less profitable method, but this has not happened yet (other reasons may be conjured up).

$$\begin{aligned} 2p_c &= 1 \\ \pi &= R(1-w) \end{aligned} \tag{4.9}$$

Thus $p_c = \frac{1}{2}$ and $\pi = \frac{1}{2}(1-w)$. Hence the real value system is now represented like this:

$$\begin{aligned} \left(1+\tfrac{1}{2}(1-w)\right) + \tfrac{1}{2}w + 2\rho &= 2 \\ \left(1+\tfrac{1}{2}(1-w)\right) + \tfrac{1}{2}w + \rho &= \tfrac{7}{4} \end{aligned} \tag{4.10}$$

We find that the rent per acre is equal to $\frac{1}{4}$, which means in physical terms $\frac{1}{2}$ ton of corn per acre; total rent is equal to $\frac{3}{4}$, in physical terms $\frac{3}{2}$ tons.[15]

In the second case, the rent is paid to the owner of the most profitable process. The value system is then:[16]

$$\begin{aligned} (1+\pi)\,2p_c + \tfrac{1}{2}w + \rho &= 4p_c \\ (1+\pi)\,2p_c + \tfrac{1}{2}w &= \tfrac{7}{2}p_c \end{aligned} \tag{4.11}$$

In order to construct the standard system, both methods have to be multiplied so that the rent disappears and that total labor remains equal to one:

$$\begin{aligned} y_1 &= 0 \\ \tfrac{1}{2}y_2 &= 1 \end{aligned} \tag{4.12}$$

We find that $y_1 = 0$ and $y_2 = 2$. Hence the standard system is the following:

$$(1+\pi)\,4p_c + w = 7p_c \tag{4.13}$$

The maximum rate of profit is thus $R = \frac{3}{4}$. If the numeraire is the standard commodity, we have:

$$\begin{aligned} 3p_c &= 1 \\ \pi &= R(1-w) \end{aligned} \tag{4.14}$$

Hence $p_c = \frac{1}{3}$ and $\pi = \frac{3}{4}(1-w)$. Thus the real value system is now represented like this:

$$\begin{aligned} \left(1+\tfrac{3}{4}(1-w)\right)\tfrac{2}{3} + \tfrac{1}{2}w + \rho &= \tfrac{4}{3} \\ \left(1+\tfrac{3}{4}(1-w)\right)\tfrac{2}{3} + \tfrac{1}{2}w &= \tfrac{7}{6} \end{aligned} \tag{4.15}$$

We find that the (total) rent is equal to $\frac{1}{6}$, which means in physical terms $\frac{1}{2}$ ton.

We thus find that both cases for the distribution of the rent lead to two different systems of value, with two different standard systems, maximum rate

[15] Using the standard commodity as the numeraire, the rent is independent from distribution; but this ceases to be the case as soon as an other numeraire (for instance $w = 1$) is chosen.

[16] In such a simple system, we can already know that the first method is the most profitable, and thus that it will seize the rent. In more complex system, we have first to calculate the prices of production for each possible case: the most profitable process is then the one which, when it is not inserted into the standard system, earns a positive rent.

of profit, and physical total rents. The problem then is that when we take a "photograph" of the market place, it is not possible to know how the rent is distributed. In order to know that, one has to investigate the institutions governing the system.

4.3 Exhaustible resources

As is well known, Sraffa's theory (Sraffa, 1960) of prices deals only with produced commodities. In the case of non-exhaustible natural resources such as land, Sraffa has however shown that rent of land can also be consistently explained by his theory — the existence of rent implies the existence of more than one technique in use to produce a commodity at a moment (see Sraffa, 1960, Ch. 11). In the case of exhaustible natural resources such as oil in the ground, Sraffa (1960), however, remains silent. The silence of Sraffa on the question of how to explain the positive value of exhaustible natural resources has led many neo-Ricardian scholars to introduce Hotelling's rule into Sraffa's theory to fill this gap in his theory.[17] In this section I argue that all such attempts contradict Sraffa's fundamental theoretical position. This should be expected since Hotelling's rule is built on neoclassical foundations, which does not fit with Sraffa's theoretical foundations. I further go on to provide an alternative explanation of the changes in the conditions of production that will occur when a natural resource is exhausted, which I contend is consistent with Sraffa's theoretical foundations. In subsection 4.3.1, I briefly describe the literature that has attempted to introduce Hotelling's rule into Sraffa's theory; in subsection 4.3.2, I show that introduction of Hotelling's rule changes the system of prices in Sraffa's theory; in subsection 4.3.3, I show why these attempts are in contradiction with Sraffa's theoretical foundations; in subsection 4.3.4, I introduce my alternative explanation, which, I think, fits with Sraffa's

[17]In the marginalist paradigm, the concept of natural resources is not separated from the concept of factor of production, because all factors of production are scarce (and substitutable) resources: thus there is no specificity of the environment. Natural resources are nevertheless considered as a valid subject of research since the work of Jevons (1865) and Hotelling (1931). Jevons studies the link between the use of coal, a natural exhaustible resources, and the economic wealth of the United Kingdom: his conclusions were over-pessimistic as he underestimated importance of technological progress (see Quadrio Curzio and Pellizzari, 1999 on this point). Hotelling tried to find the rate of exploitation of a given natural resource so that social well-being is optimised. According to him, perfect competition in the market can lead to the emergence of this optimal rate of exploitation (but he was conscious that perfect competition was impossible in the case of the exploitation of real natural resources). Numerous contributions followed these seminal works, regarding the differences in the exploitation of renewable and non-renewable resources, using usually dynamic control and dynamic programming methods. The concept of social well-being is debated: some contributions focus instead on the maximisation of private well-being, on the maximisation of the profits, or on the maximisation of the rents that are seized by the owner of the natural resource. Rights and property regimes on natural resources are also discussed (Clark, 1979; Dasgupta and Heal, 1981; Fisher, 1981; Pearce and Turner, 1990).

The general rule, regarding works following Hotelling research, is that in a situation of perfect competition, the price of the exhaustible natural resource will rise because the selling of the resource should generate the same profit as its conservation. A rent should then be given to the owners of the natural resource if they decide to keep it, and thus the price of the resource increases. This increase in the price p_t is equal to the uniform rate of profit r_t of the economy at time t (Kurz, 2006) :

$$p_{t+1} = p_t\,(1 + r_t) \tag{4.16}$$

theoretical foundations; in subsection 4.3.5, I present the conclusion of this section.

4.3.1 A critique of neo-Ricardian attempts to introduce HOTELLING's rule in SRAFFA's theory

Before taking up the leading neo-Ricardian attempts to incorporate Hotelling's rule in Sraffa's theory, it may be helpful to take note of the assumptions on which Hotelling's rule is based. These assumptions are: the exhaustible resource is privately owned; the owner wants to maximize the present value of his future profits; the market rate of interest γ expresses the average degree of impatience in the economy and it is equal to the society's rate of time preference; there is perfect competition;[18] the quality of the resource is uniform and constant at any time; the stock of the underground natural resource is known; there is perfect foresight with respect to demand for the resource; it is possible to calculate the present social value of the resource, i.e. the total value enjoyed in present and future periods by the consumers of the resource; and finally, quantity produced and price $p(t)$ depend on demand and supply functions of the resource. Given these assumptions, the resource price that maximizes the present social value, when there is no extraction cost, is given by: $p(t) = p(0)\, e^{\gamma t}$. This is the price of the resource in the ground, also called 'scarcity rent' (e.g. in Solow, 1974) or 'royalty' (e.g in Devarajan and Fisher, 1981). This royalty should be added to the extraction cost in order to find the price of the extractible resource.

In this paper we do not take up the problems with Hotelling's rule itself.[19] We only focus on the reasons why it is not correct to integrate Hotelling's rule inside Sraffa's framework. Among the major contributors in this area are Kurz and Salvadori (1997; 2000; 2001; 2009), Schefold (1989; 2001), Bidard and Erreygers (2001a; 2001b) and Parrinello (1983; 2001; 2004).[20]

Kurz and Salvadori ask the question: "why the owners of such [exhaustible] resources do not sell the whole amount that they own at current prices in order

[18] This assumption is later relaxed in Hotelling's model (he investigates the case of monopoly), but this is never done in the following neo-Ricardian models.

[19] There could be first an empirical criticism about the reality of this rule. Some empirical facts are not taken into account (market imperfections, difference in ore qualities, capacity and investment constraints, exploration costs, e.g. see Krautkraemer, 1998) and empirical analyses of price do not always reflect Hotelling's rule (e.g. see Hart and Spiro, 2011).

[20] We could also add to this list Ravagnani (2008) who criticizes both backstop technology models supposing perfect foresight (models of the type of Kurz and Salvadori, 2000; Bidard and Erreygers, 2001a; Schefold, 2001), and intensive rent models making strong assumptions on the existence of a second process at each period of time allowing to calculate the rent (models of the type of Parrinello, 2001). He shows that in the case of oil industry in the US, contracts between managers and owners do not show that royalties are increasing following the rate of profit: they are actually highly dependent on norms, previously created through bargaining and power relationships. These norms can be broken when power relationships change and, in case of State ownerships, the level of royalties depends on public policy and international relationships. He therefore argues that royalties should be considered as an exogenous variable, on the same ground as the profit rate (or the wage rate).

to invest the proceeds in an industry where the normal rate of profit can be obtained" (Kurz and Salvadori, 1997). Their answer is: "the storage of natural resources, which may be considered as a 'conservation industry', cannot be operated if it does not yield a 'royalty' to the owners of the resources" (Kurz and Salvadori, 1997). They justify this precisely because they assume a long-term *equilibrium* framework: "Hotelling's rule [see Hotelling (1931)] is nothing but the application of the concept of a uniform rate of profit to all processes in the economy, whether these are conservation or production processes" (Kurz and Salvadori, 2001). Hence Kurz and Salvadori develop a dynamic Input-Output model under the assumption of free competition (which is supposed to lead to a uniform rate of profit), constant returns to scale and a given real wage rate where Hotelling's rule applies.

According to Bidard and Erreygers: "a consistent theory of exhaustible resources is needed just as much as a consistent theory of prices" (Bidard and Erreygers, 2001a). They accept Hotelling's rule and apply it in the Sraffian framework without providing any justification:

> "In order of analytical complexity, the question of exhaustible resources comes next to that of land with, however, a qualitative gap: the price of an exhaustible resource changes with time, in order to compensate his owner for waiting (Hotelling's rule)" (Bidard and Erreygers, 2001a).

They acknowledge that Hotelling's rule may be based on weak empirical basis, but they care only about theoretical consistency. They work with a small system with one commodity and one exhaustible natural resource, with no extraction cost and constant returns to scale. In my view their model has been successfully generalised by Schefold (Schefold, 2001).

Schefold (1989; 2001) is ambiguous on the use of Hotelling's rule in a Sraffian framework. On one hand, he thinks that Ricardo's theory of rent can be applied to "the extraction of most exhaustible resources" (Schefold, 2001) and rightly finds that the assumptions behind Hotelling's rule (perfect foresight on future demand, technology and stocks) are not compatible with a Classical framework if the natural resource is a basic good:

> "if the resource really gets exhausted over an intermediate time span, its price must rise; if it is a basic commodity, relative prices of other commodities must change, complicated patterns of substitution in the processes of production and of consumption may ensue in all other periods and perfect foresight becomes implausible" (Schefold, 2001).

However, on the other hand, while playing "the game of logic and [trying] to reconstruct a theory of exhaustible resources within the context of classical theory", Schefold assumes that "the rise of the price of the exhaustible resource, in the absence of technical progress, is the expression of a future decrease of the surplus available for consumption and investment" (Schefold, 2001). He also justifies this assumption on the ground that "a classical model is a long period model" (Schefold, 2001). He then constructs a model with constant returns to scale, an exhaustible resource (which could be a basic commodity) and Hotelling's rule on the price of the resource in the ground (i.e. before extraction).

Parrinello (1983; 2001; 2004) follows an interesting approach: the royalty in his case is equivalent to an intensive rent, whereas for other neo-Ricardians the royalty is seen as the profit of the conservation process. Furthermore, instead of assuming first that the royalty increases and then looking at the consequences on quantities (as in the first three models), he assumes that quantities are given and then looks at its consequence on the royalty. But then how is it possible to face the contradiction that the royalty should follow Hotelling's rule? In fact, for Parrinello, Sraffa's system of production "is assumed to be the result of profit maximizing choices under conditions of competition and long period equilibrium" (Parrinello, 2004).

He follows here the interpretation of Garegnani (1976), which says that a process of gravitation, due to perfect competition, is able to generate one uniform rate of profit and one choice of technique so that the system of production is square. However, this process of gravitation is seriously questioned by Sinha and Dupertuis (2009). Furthermore, there is no reason to accept a priori that there is "competition and profit seeking behavior" (Parrinello, 2004), if the uniformity of the rate of profit is only a convention which helps to find the standard system. From my point of view, Parrinello's model is therefore good (no assumption regarding constant returns to scale, no price on the resource not yet extracted) but there is no need to justify Hotelling's rule with it. I will now concentrate my criticism on the first three models in subsections 4.3.2 and 4.3.3, before presenting a modified version of Parrinello's model in subsection 4.3.4.

4.3.2 Introducing Hotelling's rule inside Sraffa changes the price system

Let us start with Kurz and Salvadori's model, which does not include rent (Kurz and Salvadori, 2000).

There are n commodities, and $m > n$ processes operating with constant returns to scale. The price column vector during the period of production t is written $\mathbf{p}_t$ and the line activity vector (describing the scale of operation for each process) is written $\mathbf{x}_t$. The quantity of natural resources in the ground at t is represented by a line vector $\mathbf{z}_t$. The period of production is uniform for all processes. A process j is defined by quadruplet $(\mathbf{a}_j, \mathbf{b}_j, \mathbf{c}_j, l_j)$, with $\mathbf{a}_j$ the line vector of inputs, $\mathbf{b}_j$ the line vector of outputs, $\mathbf{c}_j$ the line vector of natural non-renewable resources (before extraction) used and l_j the labor coefficient. The wage rate $\mathbf{w}$ is given in real terms (a line vector of given commodities). Assuming that there is perfect competition, the rate of profit r is uniform for all processes. Kurz and Salvadori then write down their system of equations, with $\mathbf{y}_t$ the column vector of royalties on natural resources and $\gamma\mathbf{d}$ the share of the surplus going to profit and royalties (given in proportion to a constant column vector of commodities $\mathbf{d}$):

> "for each time $t \in \mathbb{N}_0$, the following [...] equations are to be satisfied:
>
> $$\mathbf{x}_{t+1}\mathbf{B}\mathbf{p}_{t+1} = \mathbf{x}_{t+1}\left[(1+r_t)\left(\mathbf{A}\mathbf{p}_t + \mathbf{C}\mathbf{y}_t\right) + \mathbf{l}\mathbf{w}\mathbf{p}_{t+1}\right] \tag{4.17}$$
>
> $$\mathbf{B}\mathbf{p}_{t+1} \leqq (1+r_t)\left(\mathbf{A}\mathbf{p}_t + \mathbf{C}\mathbf{y}_t\right) + \mathbf{l}\mathbf{w}\mathbf{p}_{t+1} \tag{4.18}$$
>
> $$\mathbf{z}_{t+1}\mathbf{y}_{t+1} = (1+r_t)\,\mathbf{z}_{t+1}\mathbf{y}_t \tag{4.19}$$
>
> $$\mathbf{y}_{t+1} \leqq (1+r_t)\,\mathbf{y}_t \tag{4.20}$$
>
> $$\mathbf{x}_t\left(\mathbf{B} - \mathbf{l}\mathbf{w}\right)\mathbf{p}_t = \left(\mathbf{x}_{t+1}\mathbf{A} + \gamma\mathbf{d}\right)\mathbf{p}_t \tag{4.21}$$
>
> $$\mathbf{x}_t\left(\mathbf{B} - \mathbf{l}\mathbf{w}\right) \geqq \mathbf{x}_{t+1}\mathbf{A} + \gamma\mathbf{d} \tag{4.22}$$
>
> $$\mathbf{z}_t\mathbf{y}_t = \left(\mathbf{x}_{t+1}\mathbf{C} + \mathbf{z}_{t+1}\right)\mathbf{y}_t \tag{4.23}$$
>
> $$\mathbf{z}_t \geqq \mathbf{x}_{t+1}\mathbf{C} + \mathbf{z}_{t+1} \tag{4.24}$$
>
> $$\gamma > 0,\ \mathbf{p}_t \geqq \mathbf{0},\ \mathbf{y}_t \geqq \mathbf{0},\ \mathbf{z}_t \geqq \mathbf{0},\ \mathbf{x}_{t+1} \geqq \mathbf{0} \tag{4.25}$$
>
> " (Kurz and Salvadori, 2000).

Eq. 4.17 means that there is production only if the equilibrium rate of profit is obtained. Eq. 4.18 means that it is not possible to obtain more than the equilibrium rate of profit by producing a commodity. Extracting a natural resource is here equivalent to the production of a commodity, so extraction costs are possible, and there is extraction only if the equilibrium rate of profit is earned from this activity.

Eq. 4.19 means that there is storage of natural resources only if the equilibrium rate of profit is earned from it. Eq. 4.20 means that it is not possible to earn more than the equilibrium rate of profit by storing natural resources. Eq. 4.21 and Eq. 4.22 mean that if a commodity is produced without being used in production or consumed in the next period, its price falls to zero. Eq. 4.23 and 4.24 mean that if a natural resource is stored without being used in production or stored again in the next period, its royalty falls to zero.

Furthermore Kurz and Salvadori assume *given amounts of commodities* and exhaustible resources available at time 0. Their model is therefore similar to a neoclassical system of linear programming, with an optimization program in order to choose the most efficient technological pathway (we can find a similar model in Pasinetti, 1975, Appendix to chapter 6). With Kurz and Salvadori's model, prices are not then Sraffian production prices, but more correctly allocated prices: initial resources are given and prices reflect the efficient allocation of scarce goods. Given the initial set of natural resources and commodities, their problem is to choose the technology so that they obtain a uniform rate of profit, zero price for excess supply, and so that effective demand is satisfied (represented by the wage, which is given in real terms and constant over time, and by profits and royalties, that are also given in real terms and constant over time). Prices and royalty depend on the allocation of a given set of resources and can be seen as a kind of scarcity index (price is equal to zero if there is overproduction and royalty is equal to zero if there is over-conservation). Whereas in Sraffa, prices depend only on the production level and on the distribution of the surplus (between wage and profit) at the given period and there can be a strictly positive price even if there is overproduction (Pasinetti, 1975, Appendix to chapter 6).

Now from equation Eq. 4.19 and equation Eq. 4.23 we get:

$$\mathbf{z}_{t+1}\mathbf{y}_{t+1} = (1+r_t)\left(\mathbf{z}_t - \mathbf{x}_{t+1}\mathbf{C}\right)\mathbf{y}_t \tag{4.26}$$

We can then add equation Eq. 4.19 and equation Eq. 4.26, and we get, through simplifications:

$$\mathbf{x}_{t+1}\mathbf{B}\mathbf{p}_{t+1} + \mathbf{z}_{t+1}\mathbf{y}_{t+1} = (1+r_t)\left(\mathbf{x}_{t+1}\mathbf{A}\mathbf{p}_t + \mathbf{z}_t\mathbf{y}_t\right) + \mathbf{x}_{t+1}\mathbf{l}\mathbf{w}\mathbf{p}_{t+1} \tag{4.27}$$

Now from equations Eq. 4.17 and Eq. 4.21 we get:

$$\mathbf{x}_{t+1}\mathbf{A}\mathbf{p}_t = \mathbf{x}_t\left(\mathbf{B} - \mathbf{l}\mathbf{w}\right)\mathbf{p}_t - \gamma\mathbf{d}\mathbf{p}_t \tag{4.28}$$

We can then add equations Eq. 4.27 and Eq. 4.28, and we get:

$$\mathbf{x}_{t+1}\mathbf{B}\mathbf{p}_{t+1} + \mathbf{z}_{t+1}\mathbf{y}_{t+1} = (1+r_t)\left[\mathbf{x}_t\left(\mathbf{B} - \mathbf{l}\mathbf{w}\right)\mathbf{p}_t - \gamma\mathbf{d}\mathbf{p}_t + \mathbf{z}_t\mathbf{y}_t\right] + \mathbf{x}_{t+1}\mathbf{l}\mathbf{w}\mathbf{p}_{t+1} \tag{4.29}$$

This equation Eq. 4.29 shows the relation between the value of inputs and the value of outputs of the system. This relation is close to the one suggested by Schefold (2001), itself a generalization of Bidard and Erreygers proposition (Bidard and Erreygers, 2001a). With only one natural resource entering into the production of only one commodity i, Eq. 4.29 is written in Schefold's system as:

$$p_{i,t} + z_{t+1}y_{t+1} = (1+r)\left[\mathbf{a}_i\mathbf{p}_t + z_t y_t\right] + w_t l_i \tag{4.30}$$

But while in Kurz and Salvadori model the value of the royalty depends on initial endowments, in Schefold model the value of the royalty depends on a backstop technology (the technology which can replace the technology using the exhaustible resource) and the expected life of the mine. The royalty is calculated at the period of exhaustion, then backward until the initial period through the assumption of Hotelling's rule. In some sense, both models are back-stop technology models: however in the first one the existence of a backstop technology is just an hypothesis in order to save the economy from destruction whereas in the second model, a backstop technology is mandatory in order to solve the system.

However, the fact that a future technology is needed to solve the value problem in the present period is clearly in contradiction with the way Sraffa constructed his model, prices being entirely dependent on present technology and present distribution. Parrinello (2004) rightly observes that in Kurz and Salvadori and Schefold models, "the determination of equilibrium prices is not self-contained in each period because of special intertemporal link". In Kurz and Salvadori, value is related to the initial endowments (this is why we can talk about allocated prices, and not about prices of production) and in Schefold, value is related to the future back-stop technology (a change in this technology causes a change in the value of the royalty in the present).

We can therefore see that:

1. Kurz and Salvadori, as well as Schefold and Bidard and Erreygers, start from the fact that royalties exist, but they do not explain why it is so, and their models do not show it either.

2. They then say that it is possible to earn a rate of profit from the natural resource storage activity, because otherwise owners of such capital should sell everything at the first period.

3. Equilibrium assumption then ensures that the rate of profit that is earned by storing natural resources is the equilibrium one. Thus Hotelling's rule is deduced from this assumption (albeit from two different methods).

4. Finally this has an impact on relative prices, especially if one natural resource is used in the production of one basic good (see subsection 4.3.6).

I will explain in the next subsection why the first three points (existence of royalties, profit on conservation industry and equilibrium assumption) do not fit in the Sraffian framework.

4.3.3 Is introducing Hotelling's rule a change in the Sraffian direction?

4.3.3.1 Theory of value

The reasons why Hotelling's rule cannot be applied in a Sraffian framework lie in the notion of 'royalty' in Hotelling and the way Sraffa defines value. For Hotelling, royalty comes from the fact that natural resource (not yet extracted) is seen as capital.[21] But why is it seen as capital? It is so because in the future

[21]"How much of the proceeds of a mine should be reckoned as income, and how much as return of capital?" (Hotelling, 1931, p. 139).

it may be possible to earn something by extracting the natural resource. Value comes from expectations - a subjective consideration.

Furthermore royalty is sometimes renamed as the "cost of use" of the exhaustible resource, or "the user cost".[22] It means that we are giving up future profits by using the resource now; the royalty is rewarding owners of the natural resource for future consumer's satisfaction, otherwise everybody would extract everything now. However, Sraffa's prices reflect only past[23] and present exchanges, not future ones.

Actually the work of Sraffa goes as this (I follow here the new interpretation of Sinha, 2012):

1. It is a description of the real market at one moment of time;
2. The only magnitudes taken into account are objective magnitudes: physical quantities of commodity inputs and employed human labor used and physical quantities of outputs;
3. The system of value can then move with one degree of freedom: this is closed when the wage (or the rate of profit) is fixed in an exogenous way.

Hence there is no room for expectation from the agents: no subjective data are taken into account. The essential theory of value behind Hotelling's rule does not therefore fit with Sraffa's theory.

4.3.3.2 The conservation industry

Royalties in Hotelling can be seen as the profit of the conservation industry (Kurz and Salvadori, 1997). This is a strange industry: there is no worker, and no need for inputs from other industries. Apparently there is no creation of value by keeping a resource in the ground, but in Hotelling's theory, owner of a stock of exhaustible resources should earn royalties on conservation.

This is not in agreement with Sraffa's value theory. Pasinetti shows that it is possible to reduce "prices of every commodities into a sum of profit weighted quantities of labor" (Pasinetti, 1973), even in case of joint production. But this reduction is not possible anymore if an industry is not using labor. Thus political economy, from the point of view of Marx and Sraffa, should be abandoned. In their approaches, the economic value comes from socially approved labor: by giving value to a resource kept in the ground without labor, we are changing the theory of value. Now every good can be a source of economic value as long as it can be a source of user value: and then every owner of such goods could ask for a reward on his conservation industry. If we allow Hotelling's rule, then

[22]"The exhaustible resource is commodity n [...] Its value in use is the same as that of its future substitute in that both render the same services to all users of the commodity" (Schefold, 2001). "The cost of production of the commodity is equal to its cost of extraction plus a user cost (due to the prospective exhaustion of the ore in the ground)" (Schefold, 2001).

[23]In the case of fixed capital, with a longer life-span than one period of production.

we allow the neoclassical theory of value starting from Menger, Jevons and Walras, and the distribution theory behind it.

Furthermore, adding a conservation industry in the system of equation would mean either that, if the extracted resource is a basic commodity, the whole system becomes a non-basic set of processes compared to the conservation industry, which would become the only basic process; or that we have two independent subsystems. This conservation industry does not need any input, so it is not dependent on any other industries and it must be a basic industry. In any case, its rate of profits should be zero if there are no inputs, because profits "must be distributed in proportion to the means of production" (Sraffa, 1960, § 4).

4.3.3.3 The result of equilibrium due to perfect competition

Finally, for Hotelling and his followers, perfect competition gives us a uniform market rate of interest and this allows us to adequately discount future profits and to find Hotelling's rule. However, for Sraffa there is no equilibrium a priori.[24] This is best illustrated by this draft 'Preface' of Sraffa's book, Production of Commodities by Means of Commodities:

> "This is not proposed as a complete system of equilibrium. The data assumed are not sufficient to determine either distribution or values. Only the effects of hypothetical, arbitrarily assumed extra data (such as wages, or the rate of profits) are discussed. ... It is offered as a preliminary and there is no a priori reason why, on the basis of it, an equilibrium system should be built: there is some room left for it, as this is confessedly indeterminate; but the question is whether there is room enough for the marginal system." (D3/12/46:20, dated 2 April 1957; quoted in Sinha, 2013)

In a Sraffian framework prices should not therefore be inferred from subjective appreciation, but only from observable data (quantities exchanged). Sraffa was so determined in this direction that he was even reluctant to use the amortisation technique on fixed capital (Kurz and Salvadori, 2005). However, Hotelling's rule $\mathbf{y}_{t+1} = (1 + r)\mathbf{y}_t$ is not an observable data. This rule may be inferred from observable data: this is precisely what Parrinello (2004) tries to do, incorporating royalty as an intensive rent, and then showing that a given technological path could allow the rent to evolve in a way consistent with Hotelling's rule. But Hotelling's rule cannot be given in the premises without breaking Sraffa's position on the theory of value.

[24]The main argument for the theory of equilibrium in Sraffa's work is that he was reasoning with a uniform rate of profit. But actually this uniform rate of profit in Sraffa's equations is not the result of a gravitation process, i.e. it is not an equilibrium rate of profit, but rather an ex-post accounting rate of profit of the real economy under study during one period of production - i.e. a conventional rate of profit, the meaning of it being that we can construct the standard system only with a uniform rate of profits (Sinha, 2012).

4.3.4 What could be a Sraffian proposition on exhaustible natural resources

I will argue here that Sraffa's system, without introducing any subjective notion and assumption on equilibrium, is able to take into account the changes in the conditions of production that will occur when a natural resource is exhausted.

4.3.4.1 The question of constant return to scale

One (irrelevant) criticism against Sraffa's system is its use of the assumption of constant returns to scale (e.g. see Solow, 2014). In this regard, an easy criticism was put forward by Menger (1871): if constant returns to scale is assumed then given an exhaustible natural resource of uniform quality and uniform location, the resource price after extraction will remain the same even if it becomes exhausted. However, Sraffa's model should not be confused with Leontief one, or with the theory of Ricardo: Sraffa warned explicitly that no assumption regarding constant returns to scale is made in his work (see Sraffa, 1960, p. v).

Should we assume constant returns to scale in the case of extraction of exhaustible resources?[25] Firstly, constant returns are extremely rare, if not non-existent, in the case of natural resource extraction. The general law is that the more a resource becomes scarce, the more difficult is its extraction (this is true for all extractive industries, but also forestry, fishery, etc.).[26]

Secondly, here is what happens when the natural resource becomes scarce: either demand remains at the same level or the demand decreases (the commodity is substituted with another good). If the demand remains high, either a new technique of production will be introduced in order to satisfy the demand, giving rise to a rent on the more profitable technique, or the system will break down. Menger's criticism is not therefore valid because, for any given exhaustible resource, it is really unlikely that we observe constant returns to scale for its extraction and, at the same time, that no second technique for the extraction would appear to answer the demand.

I present below a model of an exhaustible resource, e.g. coal. A commodity is produced, so a natural resource becomes a commodity only after extraction: in our case I make the distinction between the natural resource conserved in the ground "Coal", which bears no price, and the commodity "Extracted Coal".

4.3.4.2 Two processes, constant returns to scale

Let us first have one mine of Coal, privately owned. Let us say that Extracted Coal is a basic commodity, entering in the production of its own process of production as well as in the process of production of wheat; and let us first

[25] The assumption of zero cost of extraction is just one example of the assumption of constant returns to scale in this case.

[26] One exception could be the case where all lands are cultivated and some disappear because of urban expansion.

assume that there are constant returns to scale operating in both industries. Table 4.2 shows the system of production.

Table 4.2: system of production of wheat and Extracted Coal, constant returns to scale.

Input			Outputs	
Wheat	Extracted Coal	Labor	Wheat	Extracted Coal
a_{11}	a_{12}	l_1	b_{11}	0
a_{21}	a_{22}	l_2	0	b_{22}

The productivity of the extraction of Coal depends on the initial amount of Coal in the mine, $C(0)$. It is assumed that we have the extraction function Eq. 4.31:

$$b_{22} = \alpha C(0) \tag{4.31}$$

With α a constant and $0 < \alpha < 1$.

The system of price is then:

$$b_{11} p_1 = (1+r)(a_{11} p_1 + a_{12} p_2) + l_1 w \tag{4.32}$$

$$\alpha C(0) p_2 = (1+r)(a_{21} p_1 + a_{22} p_2) + l_2 w \tag{4.33}$$

With r the uniform rate of profit, and w the wage. We have then an expression of the prices of extracted coal and wheat which are independent both from time and, more importantly, from the quantity of resource left in the ground:

$$p_1 = \frac{(1+r) a_{12} p_2 + l_1 w}{b_{11} - (1+r) a_{11}} \tag{4.34}$$

$$p_2 = \left[\frac{(1+r) a_{21} l_1 w}{b_{11} - (1+r) a_{11}} + l_2 w\right] / \left[\alpha C(0) - (1+r) a_{22} - \frac{(1+r)^2 a_{12} a_{21}}{b_{11} - (1+r) a_{11}}\right] \tag{4.35}$$

As I said earlier, this model is highly implausible. In real systems, cost of extraction should be correlated with the quantity of natural resource left. And as Sraffa stresses, the indication of scarcity of the natural resource can be reflected in the presence of two processes producing one commodity while at least one process is using the natural resource as an input. Let us introduce these two important modifications, first separately and then together.

4.3.4.3 Two processes, non constant returns to scale

First if we want to have a more realistic function of extraction, it should at least be in the form:[27]

$$b_{22}(t) = \alpha C(t) \tag{4.36}$$

That is, the extraction cost is positively related with the stock of coal left in the ground.

The price of extracted coal is then time-dependent:

$$p_2(t) = \left[\frac{(1+r)\,a_{21}l_1w}{b_{11}-(1+r)\,a_{11}} + l_2w\right] / \left[\alpha C(t) - (1+r)\,a_{22} - \frac{(1+r)^2\,a_{12}a_{21}}{b_{11}-(1+r)\,a_{11}}\right] \tag{4.37}$$

But we cannot say that, if distribution of the surplus between profits and wages is constant, the price of Extracted Coal will increase as the quantity of Coal $C(t)$ decreases. This is because Extracted Coal is a basic commodity: thus if the conditions of production of Extracted Coal change, the value of the numeraire will also change, and no inter-temporal comparison based on prices can be made.[28] The only possible inter-temporal comparison is to look at the maximum rate of profits of the standard system (which does not depend on prices). In order to get the standard system, we must multiply Eq. 4.32 by coefficient q_1 so that proportion of commodities in the inputs are equal to proportion of commodities in the surplus:

$$\frac{q_1b_{11}}{\alpha C(t)} = \frac{q_1a_{11}+a_{21}}{q_1a_{12}+a_{22}} \tag{4.38}$$

The maximum (or physical) rate of profit of the standard system is then:

$$R(t) = \frac{q_1b_{11}-q_1a_{11}-a_{21}}{q_1a_{11}+a_{21}} = \frac{\alpha C(t)-q_1a_{12}-a_{22}}{q_1a_{12}+a_{22}} \tag{4.39}$$

If $\alpha C(t+1) \neq \alpha C(t)$, in order to find the proportions of the new standard system, we then need to multiply Eq. 4.33 by coefficient $\frac{\alpha C(t)}{\alpha C(t+1)}$, so we get:

$$\frac{q_1b_{11}}{\alpha C(t)} = \frac{q_1a_{11}+\frac{\alpha C(t)}{\alpha C(t+1)}a_{21}}{q_1a_{12}+\frac{\alpha C(t)}{\alpha C(t+1)}a_{22}} \tag{4.40}$$

The new maximum rate of profits will then be:

[27] This idea comes from the economics of renewable resources (Gordon, 1954; Schaeffer, 1954), following a presentation from Erreygers (2014) on this subject.

[28] If Extracted Coal was a non-basic commodity, it would be possible to assess the evolution of its price in time (see Erreygers, 2014).

$$R\left(t+1\right)=\frac{q_{1}b_{11}-q_{1}a_{11}-\frac{\alpha C(t)}{\alpha C(t+1)}a_{21}}{q_{1}a_{11}+\frac{\alpha C(t)}{\alpha C(t+1)}a_{21}}=\frac{\alpha C\left(t\right)-q_{1}a_{12}-\frac{\alpha C(t)}{\alpha C(t+1)}a_{22}}{q_{1}a_{12}-\frac{\alpha C(t)}{\alpha C(t+1)}a_{22}} \tag{4.41}$$

Hence we see that if the extraction of the coal gets harder as soon as $C\left(t\right)$ decreases, the maximal physical rate of profits will decrease.

4.3.4.4 Three processes, constant returns to scale

Secondly, let us go back to the first case where the extraction function is represented by Eq. 4.31. If the extraction of coal cannot satisfy the demand, it allows for a new technique to come into play, e.g. production of Synthetic Coal, as in table 4.3:

Table 4.3: system of production of wheat, Extracted Coal and Synthetic Coal, with constant returns to scale.

Inputs			Outputs	
Wheat	Coal	Labor	Wheat	Coal
a_{11}	a_{12}	l_1	b_{11}	0
a_{21}	a_{22}	l_2	0	b_{22}
a_{31}	a_{32}	l_3	0	b_{32}

Now, as Synthetic Coal and Extracted Coal have the same price, in order to solve the price system a rent has to be added. There are various ways to do it, depending if the new technique is more profitable (technological improvement), less profitable (expression of a real scarcity) or if the rent is captured by the owner of the mine or by the workers. We will assume that the new technique is less profitable and that rent ρ goes in the pocket of the mine owner:

$$b_{11}p_{1}=\left(1+r\right)\left(a_{11}p_{1}+a_{12}p_{2}\right)+l_{1}w \tag{4.42}$$

$$\alpha C\left(0\right)p_{2}=\left(1+r\right)\left(a_{21}p_{1}+a_{22}p_{2}\right)+l_{2}w+\rho \tag{4.43}$$

$$b_{32}p_{2}=\left(1+r\right)\left(a_{31}p_{1}+a_{32}p_{2}\right)+l_{3}w \tag{4.44}$$

The price of the Extracted Coal/Synthetic Coal and the rent are then:

$$p_{2}=\left[\frac{\left(1+r\right)a_{31}l_{1}w}{b_{11}-\left(1+r\right)a_{11}}+l_{3}w\right]/\left[b_{32}-\left(1+r\right)a_{32}-\frac{\left(1+r\right)^{2}a_{12}a_{31}}{b_{11}-\left(1+r\right)a_{11}}\right] \tag{4.45}$$

$$\rho = \left[\alpha C(0) - (1+r)\,a_{22} - \frac{(1+r)^2\,a_{12}a_{21}}{b_{11} - (1+r)\,a_{11}}\right] p_2 - \left[\frac{(1+r)\,a_{21}l_1}{b_{11} - (1+r)\,a_{11}} + l_2\right] w \tag{4.46}$$

This rent is once again not time-dependent.

4.3.4.5 Three processes, non constant returns to scale

However, now if we want to add both modifications, when the extraction function is represented by Eq. 4.36, the system of price becomes:

$$b_{11}p_1(t) = (1+r)\left[a_{11}p_1(t) + a_{12}p_2(t)\right] + l_1 w \tag{4.47}$$

$$\alpha C(t)\,p_2(t) = (1+r)\left[a_{21}p_1(t) + a_{22}p_2(t)\right] + l_2 w + \rho(t) \tag{4.48}$$

$$b_{32}p_2(t) = (1+r)\left[a_{31}p_1(t) + a_{32}p_2(t)\right] + l_3 w \tag{4.49}$$

And then price of the Extracted Coal/Synthetic Coal and rent become:

$$p_2 = \left[\frac{(1+r)\,a_{31}l_1 w}{b_{11} - (1+r)\,a_{11}} + l_3 w\right] / \left[b_{32} - (1+r)\,a_{32} - \frac{(1+r)^2\,a_{12}a_{31}}{b_{11} - (1+r)\,a_{11}}\right] \tag{4.50}$$

$$\rho(t) = \left[\alpha C(t) - (1+r)\,a_{22} - \frac{(1+r)^2\,a_{12}a_{21}}{b_{11} - (1+r)\,a_{11}}\right] p_2 - \left[\frac{(1+r)\,a_{21}l_1}{b_{11} - (1+r)\,a_{11}} + l_2\right] w \tag{4.51}$$

Now an interesting feature of it is that the price of Extracted Coal and Synthetic Coal is not time-dependent, as this price depends on the third technique (the least profitable one - Synthetic Coal production). Thus the standard system is only composed by the Synthetic Coal and the Wheat processes, and the standard surplus does not change over time. Only the rent is time-dependent, and the rent decreases as the extraction cost increases. If the extraction cost gets too high, the Synthetic Coal process could become more profitable than extracting coal from the ground: at that point, the rent will become negative, meaning that it will be earned by the owner of the Synthetic Coal process.

4.3.5 Concluding comments

The price of the Coal mine could depend on the rent that the buyer expects to get (using the rate of profit as a depreciation rate for future profit). The current rent and profit rate can be calculated by Sraffa's method. In case of an arbitrage between two competitive investments, a calculation of the value of the Coal mine could be:

$$p_{mine} = \int_{0}^{\infty} \left[r\left(t\right) \alpha C\left(t\right) p_2\left(t\right) + \rho\left(t\right) \right] x_2\left(t\right) e^{-r(t)t} dt \tag{4.52}$$

With $x_2(t)$ the intensity of the extraction process. And from that one could argue that the value of Coal in the ground is $v_{Coal} = p_{mine}/C(t)$. But this calculation cannot be done without some expectations on future rate of profit, future demand and future prices. On that subject Sraffa cannot help, so the price of the mine, as well as price of Coal as a natural resource not extracted yet (or price of a land not cultivated yet) should remain indeterminate within the bare Sraffian framework.

An assumption about what future rates should be applied may be conventionally given. These rates do not have to be the same as the rates that actualize in the future; for example, 20 years of current prevailing rent used to be the convention to determine the price of land at the present. Starting from this convention, price of natural resource into the ground can then be found. But then we have a conventional price and it should be pointed out that neither it reflects the “true value” of the resource, nor its “cost of use”.

We found here again the difference between the value theory of the Austrian school and of Hotelling and the value theory of Sraffa. According to the first ones, if one land is used in one process of production, thus, not only this land, but all land have a value, defined by the consumer’s satisfaction that we can create with this land (now and in the future – this is why even a not yet used land can receive a royalty). Hotelling was in the same line of thought when he was assuming a royalty on conservation process. However, for Sraffa, value derives only from production, and land not used in production cannot receive a rent.

The analysis in subsection 4.3.4 can easily be widened to other natural resources: land of course, but also renewable resources. There is still lot of work to be done in order to understand the relationships between rents and biophysical limitations of natural resource extractions.

4.3.6 Appendix

Here I prove that there is a change in relative prices when Hotelling’s rule is introduced in a Sraffian framework, starting from Kurz and Salvadori’s model, described in subsection 4.3.2.

Let us suppose that wages are set to zero (hence the rate of profit r_t becomes the maximum rate of profit R_t). As coefficients of production are constant, we can clearly see that the price system is changing when we add Hotelling’s rule. If there were no Hotelling’s rule then Eq. 4.27 would be written as:

$$\mathbf{x}_{t+1}\mathbf{B}\mathbf{p}_{t+1} = \left(1 + R_t\right) \mathbf{x}_{t+1}\mathbf{A}\mathbf{p}_t \tag{4.53}$$

The scarcity of the natural resource is not taken into account anymore: if the resource gets scarcer the activity level will be lower for those processes using (directly or indirectly) the natural resource. But because constant returns to scale are assumed, the price relation would not change. As the technology is not changing, the maximum rate of profit has no reason to change from time to time, so we can change the system into:

$$\mathbf{x}_{t+1}\mathbf{B}\mathbf{p}_{t+1} = (1+R)\,\mathbf{x}_{t+1}\mathbf{A}\mathbf{p}_t \tag{4.54}$$

This maximum rate of profit R is the standard rate of profit. Assuming Hotelling's rule, royalties increase from period to period and then prices may change from period to period. However, is it possible that introducing royalties does not change the standard system, and thus does not change relative prices and R? From equation Eq. 4.27 we should get:

$$\mathbf{x}_{t+1}\mathbf{B}\mathbf{p}_{t+1} = (1+R)\,(\mathbf{x}_{t+1}\mathbf{A}\mathbf{p}_t + \mathbf{z}_t\mathbf{y}_t) - \mathbf{z}_{t+1}\mathbf{y}_{t+1} \tag{4.55}$$

If introducing royalties does not change relative prices, we should have an equality between relations Eq. 4.54 and Eq. 4.55:

$$(1+R)\,\mathbf{x}_{t+1}\mathbf{A}\mathbf{p}_t = (1+R)\,(\mathbf{x}_{t+1}\mathbf{A}\mathbf{p}_t + \mathbf{z}_t\mathbf{y}_t) - \mathbf{z}_{t+1}\mathbf{y}_{t+1} \tag{4.56}$$

When simplifying, we get:

$$(1+R)\,\mathbf{z}_t\mathbf{y}_t = \mathbf{z}_{t+1}\mathbf{y}_{t+1} \tag{4.57}$$

And from equation Eq. 4.19 we obtain:

$$(1+R)\,\mathbf{z}_t\mathbf{y}_t = \mathbf{z}_{t+1}\mathbf{y}_t \tag{4.58}$$

For prices not to change with the introduction of royalties, it has therefore to be that $z_t = z_{t+1}$; i.e. it has to be that there should be no decrease in the stock or, in other words, that exhaustible natural resources should actually not be used. We can therefore conclude that royalties do not influence the system of price only if natural resources are not used for the production of basic goods.

4.4 Waste, pollution, and renewable resources

On the contributions that tackle environmental problems (apart from the case of exhaustible resources), some try to assess the waste treatment problem and how to take into account recycling in a Sraffian framework (Lager, 2001; Hosoda, 2001; Kurz, 2006); others attempt to take into account the pollution of a natural resource and how to implement a polluter-pay principle in a Sraffian model (Quadrio Curzio and Pellizzari, 2003); and others try to describe the management of renewable resources, when their extraction could lead to their extinction (salmon model in Kurz and Salvadori, 1995, p. 351-357, fish farming vs. fish in the wild in Erreygers, 2014).

4.4.1 Waste management and recycling

4.4.1.1 Lager

Lager (2001) deals with the following joint production problem: if two commodities are jointly produced by two different processes, it is possible that their production exceeds the requirement for use (or the effective demand if they are only consumption goods). What would then be their prices? Is there free or costly disposal?

According to Lager the solution is to add a third process using the commodity in excess production (for instance product 1) in order to produce the second commodity (for instance product 2). He says that this process could be considered as "a costly disposal process which absorbs some quantities of the unwanted product 1 and produces some quantities of product 2 by means of labor". Hence product 1 will have a negative price: "the producers of bads have to pay for delivery and the users of the bad obtain revenues for taking the unwanted product, i.e. the price of the bad is negative". Lager also makes reference to physical laws of nature, such as "the principle of conservation of mass-energy" to explain why the rule of free goods, or of free disposal, should be discarded, and why wastes (or "bads") should explicitly appear in the equations of production.

He then develops a model where there are three possibilities for a waste producer:

> "someone who produces potential bads has several options: (i) he may find somebody who takes the product, (ii) he may buy costly permits and use the right to dispose of excess production, or, if that is technically feasible, he may (iii) use an alternative method which is more expensive but by which excess production can be avoided or, at least, reduced" (Lager, 2001).

If the disposal does not exceed tolerated levels for environmental protection, permits of disposal are free. Otherwise, the law of supply and demand set a positive price for permits. The free competition is also assumed in the market (whereas in the new interpretation - or in the work of Pasinetti - it is not necessarily the case), and he develops a cost-minimizing system with land and renewable resources, which is in the same spirit as the one developed by Kurz and Salvadori (2000).

I am reluctant to adopt this idea of a negative price, as I think that a price is given to commodity as soon as it is exchanged on the market. I think the solution is to say that, if they must dispose of the surplus, they will buy a service for disposal; if they do not need such service, i.e. if disposal is not costly, the waste will not appear in the equations (see subsection 4.4.1.3 for mathematical representation of this point and subsection 4.4.1.4 for a development). The laws of nature such as thermodynamic laws actually represent strong constraints for the economic process, and these constraints must be taken into account if one is interested in the dynamics of a system of production; but it is important to note that in order to calculate static Sraffian prices, there is no need to consider them. As Sraffa's system is an economic one looking at commodities (goods and services) exchanged in a market, there is no need to consider what is not exchanged in the market for the price calculation.

4.4.1.2 Hosoda

Hosoda (2001) thinks that Sraffian economics are static long-run equilibrium economics and that prices gravitates around long-term equilibrium prices. However, for him "dynamic factors are also important", and that why he is interested into exhaustible resources and waste management.

He develops a model in the spirit of the corn-guano model developed by Bidard and Erreygers (2001a) where waste, produced by process 1, must be disposed of in a landfill (process 2) or recycled (process 3). Landfill is considered as an exhaustible resource, so at one moment in time recycling will be the only option left - recycling is the back-stop technology. As recycling is assumed less productive than landfilling, recycling is not activated until landfilling is not possible anymore. Hosoda adds that "residuals must have a negative price".

Process 1 at the beginning buys the service of landfilling. As landfill is exhausted, the price of landfilling then increases: here Hosoda makes reference to the Hotelling's rule to justify this increase. At the end of the landfill, the recycling process becomes equally profitable and will replace landfilling.

On the "negative price" solution for the bads, again see subsection 4.4.1.3 for a development of my position on this point. As regards the reference to the Hotelling's rule, see section 4.3 for a critique of such use in the Sraffian framework. I think it is possible to come up with the same result by discarding the Hotelling's rule and by assuming instead non constant returns to scale on the landfill process.

4.4.1.3 Kurz

Kurz (2006) acknowledges that the economic system is constraint by the availability of natural resources and by the physical laws governing transformations and exchanges; furthermore, following Jevons (1871), he notes that joint production is a widespread phenomenon: "multiple-products processes are ubiquitous, and joint production is the rule" (Kurz, 2006). With joint-production, processes not only produce goods, defined as "products capable of satisfying human needs and wants", but also bads, defined as "products nobody wants and which may even be harmful to humans if not disposed of safely by means of disposal processes". Negative prices are attached to bads: "while with goods, money and product move in opposite direction, with bads, the direction is the same" (Kurz, 2006).

Besides, the distinction between goods and bads cannot be known in advance: one has to look at the conditions of production and at the exchanges on the market to have the answer. But in order to calculate the price of a joint-production system, one has to ensure that there is the same number of processes and of resources used/or produced.[29]

Kurz then develops a simple model with costly disposal. Starting from one process producing one good and one waste, he first introduces costly disposal by adding one process which uses the waste as an input but produces nothing:

$$\begin{array}{lccccccc} & Labor & Good & Waste & & Good & Waste \\ Method\,1 & l_1 & a_{11} & 0 & \rightarrow & b_{11} & b_{12} \\ Method\,2 & l_2 & a_{21} & b_{12} & \rightarrow & 0 & 0 \end{array} \tag{4.59}$$

Method 2 is therefore the technology which is able to dispose of the waste. Kurz first states that this technology is used by a different industry than the one using method 1. The system of value can thus be represented in this way:

$$\begin{array}{c} (1+\pi)\,a_{11}p_g + l_1 w = b_{11}p_g + b_{12}p_w \\ (1+\pi)\,(a_{21}p_g + b_{12}p_w) + l_2 w = 0 \end{array} \tag{4.60}$$

With p_g the price of the good and p_w the price of the waste, π the profit rate and w the wage. Here the price of the waste must be negative:

$$b_{12}p_w = -a_{21}p_g - \frac{l_2 w}{(1+\pi)} \tag{4.61}$$

Kurz then states that system 4.60 is equivalent to the following system:

$$(1+\pi)\,(a_{11}p_g + a_{21}p_g) + (l_1 + l_2)\,w = b_{11}p_g \tag{4.62}$$

In this new system, the disposal of the waste is done by the same industry which produces it, and the waste does not appear in the value system anymore.

[29] Mill, for instance, discarded the classical theory of price precisely because in the case of a joint production system consisting of a single process, it is not possible to assert the prices. If we assume that it is always possible to represent the system as a square one, i.e. as "a set of industries ... equal in number ... to the different things that are produced and/or used as means of production" (Sraffa, 1960, § 90), then prices can be calculated. In case we refuse this assumption, Dupertuis and Sinha (2009) show that it is nevertheless always possible to construct the associated standard system (and thus to find for instance the maximal rate of profits).

However, actually, if both systems are equivalent on the physical level, they are not on the value level: as soon as the rate of profit is different from zero, the value of the output is different. In system 4.60, the value of the output is:

$$((1+\pi)\, a_{11} + a_{21})\, p_g + \left(l_1 + \frac{l_2}{(1+\pi)}\right) w = b_{11} p_g \tag{4.63}$$

Which representation is then the good one? They actually represent two different situations that could happen in the market: waste processing could be outsourced or handled internally. Nevertheless, in my opinion, the first representation (system 4.60) is clearly wrong, as it shows the waste as a product exchanged on the market, whereas it is the service of disposal, with its related cost, which is actually traded. Hence a good representation of a situation where the first industry, who produces the waste, outsources the disposal of its waste, would be:

$$\begin{gathered}(1+\pi)\,(a_{11} p_g + b_{12} p_d) + l_1 w = b_{11} p_g \\ (1+\pi)\,(a_{21} p_g) + l_2 w = b_{12} p_d\end{gathered} \tag{4.64}$$

Here we can see that outsourcing the disposal process is more costly for the first industry than handling it internally. But of course, if the disposal industry is specialized in this activity and experiences increasing returns to scale, it can be expected that the price of the disposal service will be cheaper.

4.4.1.4 Conclusion on waste and negative price

Negative prices should not arise in a Sraffian framework, because the latter describes the production of commodities (goods and services) that will be exchanged on a market. A positive price is given to commodity as soon as it is exchanged on the market. If the waste is disposed of by the industry who produces this waste, a cost can be attached to it: some inputs will have to be bought on the market in order to successfully dispose it of, but there will not be any exchange of the waste on the market, and thus no price. If the waste is given to an other industry which will dispose it of, the other industry is selling the disposal service, and a positive price is attached to this service, related to the costs of this industry: again, no price will appear on the waste.

This is why I argue that any Sraffian analysis should start with the definition of commodities (goods and services) that are exchanged on the market, and not by looking at physical exchanges between industries. This helps to avoid the "circular reasoning" described by Schefold that would occur when, in the second case, one tries to construct a square system without knowing which resource will receive a price:

> "But how would prices have to be derived in the joint production case, if the concept of price had not already been introduced in single product systems? Sraffa argues – having introduced prices – that a joint production system must be 'square' (consist of square input and square output matrices), because if they were more processes than there are commodities, each process represented by

an independent equation, there would be an over-determination of prices. It might be difficult to explain 'overdetermination' to readers who had not before been shown what was meant by 'prices': the reasoning would become circular. Sraffa therefore starts with single production where prices immediately 'spring . . . from the methods of production', and he thus avoids reasoning in a circle, but I do not see how he could avoid circularity if he started directly from joint production" (Schefold, 2005).

4.4.2 Pollution and the polluter-pay principle

Quadrio Curzio and Pellizzari (2003)[30] investigate the pollution of non-privately owned natural resources. They start with a Sraffian single production model defined by its matrix of technology $\mathbf{A}$, with the coefficients concerning the production of one unit of the m goods produced by the system, and its line vector of labor coefficient, $\mathbf{l}$. They then define a line vector$\mathbf{r}$, whose coefficients r_i expresses the use of a natural resource needed for the economic process i in order to produce one unit of good i (single production system). The total use of the natural resource cannot exceed quantity R, which is the total quantity of the resource existing in the environment:

$$m_R = \mathbf{ry} \leq R \tag{4.65}$$

With $\mathbf{y}$ the column vector of activity levels for all processes (equal to the vector of produced quantities $\mathbf{q}$ because only single production is allowed and because matrix is normalized so that the matrix of output is the identity matrix) and with m_R the quantity of the natural resource used in each period of production by the system.

They assume then the possibility of a recycling, or of a remediation, of the natural resource, in order to partially replenish the natural stock. This re-

[30]Quadrio Curzio (Quadrio Curzio and Pellizzari, 1999; Quadrio Curzio, 2011), from a Sraffian perspective, but with inspirations from Leontief and Von Neumann, develops a multi-sectoral model where rents and scarce resources are in the center of the analysis.

He first deals with a static model, and looks at the order of efficiency and profitability of the processes. He then studies the effect of variation of the distribution and the activity levels: he shows the important role of rent in the distribution, as it changes the relation between wage and profit. He then compares technologies, i.e. a set of techniques (with single or joint production), following several criteria: efficiency, structure, size, depending on the decrease of the resources and the increase of production. He thus defines *technological rent* as the rent which is connected with one particular technology (and not with one particular technique), and *technological scarcity* as the scarcity which exists as soon as constraints from scarce resources appear at the structural level of production. He also defines technological progress as the capacity for an economic system to reduce these constraints.

Finally, Quadrio Curzio studies the order of efficiency of different processes, in a static and dynamic way, and the way the constraints lead to the activation of certain processes and to the reduction of production growth. The evolution of rents can lead to conflicting situations between the different agents when they have to choose the processes to activate, because they have different interests (seeking for the maximal rents or for the maximal profits for instance). This situations may lead to the development of some innovations to the detriment of others.

plenishment is considered to be non complete, and its cost, in terms of inputs needed for the replenishment process, is attributed to each polluting industry, proportionally to their use of the natural resource (following the polluter-pay principle, OECD, 1972). In order to do so, they define a line vector $\mathbf{a}_R$ with coefficients a_{iR} representing the quantity of commodity i needed for the maximum possible replenishment of one unit of the natural resource. Each process consuming the natural resource, in addition with the production of their own commodity, will then have to produce the commodities needed to replenish the maximum of what they have consumed, i.e. they will have to produce vector $\mathbf{a}_R$ multiplied by coefficient r_i.

Hence remediation is treated in the same way as internal waste disposal in Kurz (2006). The only difference is that the quantity of labor L_R which is needed directly for the replenishment process is not handled by the industries: the replenishment process is operated outside of the economic system, and the wage needed for this operation is not accounted when the profitability criteria is used for the choice of technique.

Each process $\mathbf{a}_i$ must produce commodity i and the vector $r_i\mathbf{a}_R$; they can be represented in this way, with a prime for a transpose vector:

$$\mathbf{a}'_i + r_i\mathbf{a}'_R = \begin{bmatrix} a_{1i} + a_{1R}r_i & a_{2i} + a_{2R}r_i & \dots & a_{mi} + a_{mR}r_i \end{bmatrix} \tag{4.66}$$

And each labor coefficient l_i becomes:

$$l_i \left(1 + a_{1R}r_i + a_{2R}r_i + \ldots + a_{mR}r_i\right) \tag{4.67}$$

We can then construct a matrix $\mathbf{R}$ containing all inputs coefficient for the reconstitution of the natural resource:

$$\mathbf{R} = \begin{bmatrix} a_{1R}r_1 & a_{1R}r_2 & \dots & a_{1R}r_m \\ a_{2R}r_1 & a_{2R}r_2 & & \vdots \\ \vdots & & \ddots & \\ a_{mR}r_1 & \dots & & a_{mR}r_m \end{bmatrix} \tag{4.68}$$

By post-multiplying matrix $\mathbf{R}$ with the activity vector $\mathbf{y}$, we get the column vector $\mathbf{q}_R$ of the quantities produced in order to replenish the natural resource:

$$\mathbf{Ry} = \mathbf{q}_R \leq \mathbf{q} \tag{4.69}$$

Regarding the choice of techniques, two criteria could be considered: the criteria of maximal productivity (which is the higher uniform rate of surplus s - if all the surplus is reinvested, this rate is equal to the maximal rate of growth), and the criteria of maximal profitability (which is the higher rate of profit π).

As regards the first criteria, the physical system becomes, when including matrix $\mathbf{R}$:

$$[1+s]\,[\mathbf{A}+\mathbf{R}-\mathbf{I}]\,\mathbf{y}=\mathbf{0} \tag{4.70}$$

Hence we can look, for different technologies $\mathbf{A}+\mathbf{R}$, which are the ones producing the highest uniform rate of surplus. However, this criteria is only efficient if the natural resource is entirely replenished: otherwise, a choice has to be made between better replenishment of the natural resource and higher production of surplus. This choice is influenced by subjective considerations on present and future expectations: for instance, the immediate use of the natural resource could be required for developing countries, but this would lower the possibilities for the future generations to use it. Furthermore the effects of the reduction of the natural resource on the environment and on ecosystems are usually unpredictable.

As regards the second criteria, one possibility is to set a price on the natural resource, so the choice can be made regarding the reduction of economical as well as environmental costs. This price p_R could then be divided into two components: one part covers the economical cost of replenishment[31] and the other part is an estimation of the economical cost of the loss of the part of the natural resource which cannot be reconstituted, represented by the environmental rent ρ:

$$p_R=[1+\pi]\,\mathbf{p}\mathbf{a}_R+w\mathbf{l}\mathbf{a}_R+\rho \tag{4.71}$$

With $\mathbf{p}$ the line vectors of price. The price system is then represented as follows:

$$[1+\pi]\,\mathbf{p}\,[\mathbf{A}+\mathbf{R}]+w\,[\mathbf{l}+\mathbf{l}\mathbf{R}]+\rho\mathbf{r}=\mathbf{p} \tag{4.72}$$

The system is undetermined, because there are $m+3$ unknowns and m equations. Even if one distribution variable is given and a numeraire is chosen, there is one degree of liberty left. Thus the efficiency of the profitability criteria depends on the relevance of the value attributed to the environmental rent.[32]

[31] But, again, the cost of labor L_R needed for the replenishment process is not taken into account in Quadrio Curzio and Pellizzari (2003).

[32] Environmental economics tries to develop economic methods in order to properly assess the level of this rent (Pearce and Turner, 1990; Barde and Pearce, 1991; Faucheux and Noël, 1995). These methods belong to three different approaches:

1. The usual market approach analyzes transactions on the market and tries to connect market prices with the environmental resource's distinctive features. The function of production method considers the environment as one of the factors of production and looks at the influence of changes in the quality of the environmental resource on prices; the dose-response method establishes a relation between pollution and the rate of disease and can then establish the costs related to an increase in pollution; the evaluation of defensive expenditures looks at the costs generated by the mitigation or the adaptation to the environmental change.
2. The implicit market approach tries to estimate preferences and expenditures related to these preferences by looking at the behaviors in relation with the environmental resource. The hedonic pricing method looks at the influence of the environment on transactions that are more or less concerned with environmental criteria, for instance the level of house rents or the wages of people willing to work in the area. The travel cost method deduces the value of an environmental site by the travel cost of people

This leads Quadrio Curzio and Pellizzari to conclude on the impossibility to find a unique criteria for the choice of techniques as soon as one non privately owned natural resource is taken into consideration in the model: a political choice is needed.

4.4.3 Renewable resources

There are very few Sraffian works on renewable resources: interestingly, Gibson (1984) suggests that the treatment between non-renewable and renewable resources should not be different in a Sraffian framework. He is first looking at one natural exhaustible resource which is divided into numerous stocks. The cost of exploration in order to find a new stock (e.g. a new mine) can be high in case of scarce natural resources. This cost should be payed off, little by little, through the life expectancy of the stock (he refers to the process of amortisation after the payment of fixed capital, e.g. a machine or a building, Sraffa, 1960, chapter X). If the stock has a very long life expectancy, or even an infinite life (i.e. if the natural resource is renewable), then the cost of exploration is payed off during an arbitrary period of time. There is no price on the natural resource and no Hotelling's rule. Gibson's analysis is close to the Ricardian analysis on mines as a renewable natural resource given that the cost of the exploration is more or less constant (see Kurz and Salvadori, 2009 for a detailed analysis of the Ricardian methodology).

Kurz and Salvadori (1995, p. 351-357) build the Salmon model, where Salmon is a renewable resource and a non-basic commodity. They demonstrate, starting from usual assumptions about the dynamics of the stock of renewable resources, that it is possible to have a stable extraction of the resource (no change of the stock between periods), but also that the resource can be depleted. They interpret the stable position as a long-term equilibrium.

Erreygers (2014) transforms Kurz and Salvadori's previous model into a Corn-Tuna model: I will focus here on Erreygers' work. He studies fish production, looking at two different processes producing tuna, by fishing on sea (Wild Tuna Method) or through aquaculture (Farmed Tuna Method). For the first process, the stock of tuna in the sea depends on fishery efforts and population dynamics:

> "in the absence of fishing, the population P tends to grow according to its natural increase n, which can be seen as a function of the population level, i.e. $n = f(P)$. Let us assume there exists a maximum population level, L, at which the population of fish stops

who visit it.

3. Finally the constructed market approach directly asks stakeholders how they would value the natural resource, for instance what they are willing to pay in order to avoid the destruction of the resource or what they are willing to receive in order to avoid the destruction of the resource.

All these approaches are strongly criticized by some researchers of the ecological economics field (see for instance van den Bergh, 2001; Venkatachalam, 2007).

> growing, i.e. $f(L) = 0$. If there is fishing, the population changes with the difference between the natural increase and the amount of fish caught in the sea" (Erreygers, 2014).

He then adds the definition of a sustainable catch, with the effort level defined as the activity level of production of the Wild Tuna Method:

> "a catch is sustainable if the effort level ensures that the population of fish remains constant. This means that, given the population of fish, the effort level is chosen in such a way that the catch c coincides with the natural increase n" (Erreygers, 2014).

He constructs a model with five processes (corn production, wild tuna production, boats production, farmed tuna production and ponds production) and one basic good (corn). Given the actual demand and the population of tuna, he can define the activity levels of all processes. They should be so that the demand is answered and that the production can continue. On the price side, the rate of profit is uniform because "none of the available methods makes extra-profits" (Erreygers, 2014). The activity level of the method earning extra-profits is set to zero; given the rate of profit, it is possible to know the wage and the relative prices. This uniformity of the rate of profit is justified by Erreygers because he chooses to "focus on situations which correspond to the long term positions usually studied in classical theory" (Erreygers, 2014). The question he chooses to answer is: given a constant demand, is it possible to have constant prices and constant activity levels on one hand, and a sustainable catch on the other hand? He shows that this is only possible for certain levels of demand.

4.4.3.1 Discussion on Erreygers' model

Erreygers thinks that his model would not be relevant if the sea were privately owned, but actually this is not true. In his model the sea has no owner, so no rent arises on the use of the sea. When there is tuna scarcity, rent arises on fisher boats. The logic goes like this: in order to satisfy the demand there are two options, to increase the effort level (by building new boats) or to produce tuna from aquaculture. The second method generates fishes with a higher price: then a rent is earned by the Catch in the Wild method. This rent is said to go in the boats owners' pocket, because if there were enough boats, it would not have been necessary to develop aquaculture. Scarcity is then related in this case with a limited number of boats (and is called an "access-to-the-sea" scarcity by Erreygers). However, we saw in subsection 4.2.5 that there is no need to find a limiting factor to observe the rise of a rent. Rent arises as soon as two processes producing the same good, with different profitabilities, are operated together. The distribution of the rent then depends on institutional factors: fishermen would have earned the rent, if they were in a position to capture it, for instance.

And if the sea is privately owned, we are back to the case of land. If there is scarcity, then either it is possible to go on other "lands" (calling a "land" a privately owned part of the sea) and if other lands have a different productivity, an extensive rent arises. Or it is possible to make aquaculture (at a higher cost). In that second case, a rent will also arise and the relations between landowners, boat owners and fishermen will decide how this rent will be distributed. Erreygers' model therefore helps us to see that if there is a clear connection between the existence of two different processes producing the same output and rent, there is no clear connection between natural resources and rent, and between their private appropriation and rent.

Erreygers then goes on saying that:

> "The corn-tuna model therefore predicts that in a situation of growing demand the price of the renewable resource will steadily increase, until it reaches a steady equilibrium (the Good Scenario) or becomes unstable (the Bad Scenario). This may be thought of as a kind of Hotelling rule for renewable resources, but it must be kept in mind that the logic behind this rule is fundamentally different from the logic behind the Hotelling rule. The increase of the price of an exhaustible resource, such as guano in the corn-guano model, is explained by the profit-maximizing behaviour of the resource owners and occurs even when demand is not growing. In the corn-tuna model, by contrast, the price increase of the renewable resource is driven by a combination of biological and economic factors and occurs only when demand is growing" (Erreygers, 2014).

Firstly, it is not true that in Erreygers' model, the price increases only when the demand is growing: if the catch is unsustainable and the demand stable, the catch per boat will decrease and the price of the tuna will increase. Secondly, why should there be a difference in the treatment between non-renewable resources and renewable resources? And if there should be no difference, shall we adopt the treatment of Erreygers (who shows that there can be an increase of the extracted commodity price, "driven by a combination of biological and economic factor") or the Hotelling's rule (driven by "the profit-maximizing behavior of the resource owner")?

We can also find this problematic in Kurz (2006): he defines renewable resources as "resources capable of regenerating themselves provided the environment that nurtures them remains favourable". The regeneration could be represented as follows:

$$u_{t+1} = u_t + f(u_t) \tag{4.73}$$

With u_t the size of the stock of the natural resource at time t and $f(u_t)$ which could be positive or negative. It is especially negative when the extraction of the natural resource is higher than its natural replenishment. He then acknowledges that, in this case, renewable resources becomes equivalent to exhaustible resources. But, no matter if $f(u_t)$ is positive or negative, Kurz states that the price of the renewable resources is related with its cost of extraction:

"the costs connected with the use of such resources are the costs incurred in raising them" (Kurz, 2006).

However, when he talks about exhaustible resources, defined as "resources that are available in given stocks that cannot be increased" (Kurz, 2006), he assumes that if the resource gets exhausted, i.e. if $f(u_t)$ is negative, the price of the resource will have to increase over time. He justifies this assumption by introducing the Hotelling's rule: in a competitive economy, the storing of the resource "cannot be operated" if the ruling rate of profit is not earned by the owners of the exhaustible resources. There is then clearly a logical problem: why do the owners of renewable resources not claim for a royalty the year the stock is depleted? Or, on the contrary, why should someone ask for a royalty just because he owns an exhaustible resource, without any relation with the cost incurred in extracting the resource?

Following Gibson idea and Erreygers' model, we see that there is no clear separation between a renewable natural resource and an exhaustible one. Fishes in the sea are renewable as long as the catch is equal or below the increase of population. This definition may apply to all natural resources. For instance with oil: in this case, the increase of the oil stock is so slow that we could say it is close to zero. The sustainable catch for an exhaustible resource like oil is then also close to zero.

Erreygers introduces a relation between the catch and the effort level: the former is equivalent to an extraction rate while the latter is equivalent to a cost of extraction. Each natural resource can therefore be defined by a stock (population P in the case of fish), a sustainable catch ($c^*(P) = g(P, e^*(P))$, with $e(P)$ the effort needed to achieve the catch) and an actual catch ($c = g(P, e)$). If the actual catch is higher than the sustainable catch, the natural resource is exhausted. Otherwise, the resource can still be called renewable.[33]

4.4.3.2 A simplified version of Erreygers' Corn-Tuna model

Let us construct a simplified version of Erreygers' model. There are three processes: a corn production process producing corn with corn and labor, a Wild Tuna Method producing tuna with corn and labor and a Farmed Tuna Method producing tuna with tuna, corn and labor. The three processes are described in table 4.4, with a_{ij} the input coefficients and b_{ij} the output coefficients, all coefficients being positive:

[33] It should be noted that depending on the population function and the catch function, there may be constant returns to scale or not. In the case of Erreygers' model, there are not. But that shall not be a problem in the New Interpretation of Sraffa, as it is underlined than Sraffa is not making any assumption on returns to scale in *PCMC*.

Table 4.4: Processes in the simple Corn-Tuna Model (simplification from Erreygers, 2014)

Inputs					Outputs	
	Corn	Tuna	Labor		Corn	Tuna
Corn process	a_{11}	0	l_1	$\rightarrow$	b_{11}	0
Wild Tuna Method	a_{21}	0	1	$\rightarrow$	0	$b_{22,t}(P_t)$
Farmed Tuna Method	a_{31}	a_{32}	1	$\rightarrow$	0	b_{32}

For the Wild Tuna Method, the stock of tuna in the sea depends on fishery and on population dynamics. The relation between the increase of population n and the population level of tuna in the sea P is described by equation 4.74:

$$f(P) = k_1 P (L - P) \tag{4.74}$$

With L the maximum population level; the maximum sustainable yield is equal to $k_1 \left(\frac{L}{2}\right)^2$. The relation between the catch per fishermen and the population P is described by equation 4.75:

$$b_{22,t}(P_t) = k_2 P_t \tag{4.75}$$

With k_1 and k_2 two positive constants. These two equations are the same as in Erreygers' model (Erreygers, 2014; Schaeffer, 1954; Gordon, 1954). The whole catch, defined as the catch per fishermen multiplied by the activity level of the Wild Tuna Method (equal to the number of employed fishermen), is sustainable if it is lower or equal to the increase of population:

$$y_{2,t} b_{22,t} \leq k_1 P_t (L - P_t) \tag{4.76}$$

The maximal number of fishermen is then defined by relation 4.77:

$$y_{2,t}^{max} = \frac{k_1 L}{2k_2} \tag{4.77}$$

We can then follow Erreygers saying that "any catch below the maximum sustainable yield can be sustained either by a large population (and hence a low effort level) or by a small population (and hence a high effort level)" (Erreygers, 2014).[34]

The quantity equations are then:[35]

$$y_{1,t} b_{11} = y_{1,t} a_{11} + y_{2,t} a_{21} + y_{3,t} a_{31} + d_{1,t} \tag{4.78}$$

[34] Hence there are two possible equilibria: the first (large population) is stable because if there is a slight increase (reciproc. decrease) of the catch, the increase of population will be bigger (reciproc. smaller). The second equilibrium is unstable.

[35] Here I do not follow Erreygers, because he is going away from an analysis of a system in one moment of time, writing that outputs must be equal to the sum of aggregate inputs of the next period and net demand of the current period.

$$y_{2,t}b_{22,t} + y_{4,t}b_{32} = y_{3,t}a_{32} + d_{2,t} \tag{4.79}$$

With $d_{1,t}$ and $d_{2,t}$ the net demands for corn and tuna in period t, $y_{1,t}$ the activity level of the corn process and $y_{3,t}$ the activity level of the Farmed Tuna Method, equal to the number of employer farmers.

If the activity levels of the two processes of tuna production are both strictly positive ($y_2 > 0$, $y_3 > 0$), a rent has to arise. Here we touch a very important point: we have two methods producing the same good, with different productivities, so a rent must arise. However, who should earn the rent? Should it be the workers, an hypothetical sea owner, an other agent? Here exchanges cannot help to decide how to write the equations, because it depends on local institutions.

Let us assume the following institutional framework:

- the sea is not privately owned so there could be no rent on the sea.
- the workers are in position to capture the rent if both methods of producing tuna are used.

Besides that, corn is the numeraire ($p_{1,t} = 1, \forall t$), and the profit rate r is defined in an exogenous way constant and uniform.

The price equations are then, with wages paid after the production process:

$$b_{11} = (1 + r)\, a_{11} + l_1 w \tag{4.80}$$

$$b_{22,t}p_{2,t} = (1 + r)\, a_{21} + w + y_2\rho_t \tag{4.81}$$

$$b_{32}p_{2,t} = (1 + r)\,(a_{31} + a_{32}p_{2,t}) + w + y_3\rho_t \tag{4.82}$$

With $p_{2,t}$ the tuna price, w the wage, and ρ_t the rent on labor (if $y_{3,t} = 0$ or $y_{2,t} = 0$, $\rho_t = 0$).

If $y_{3,t} = 0$, we have a Wild Tuna System. If $y_{2,t} = 0$, we have a Farmed Tuna System. As both systems have the same standard system, the wage rate is the same in both of them (only the corn process is basic). It is then possible to compare the price of the tuna produced in both cases (the cheapest produced tuna reveals the better system). There is finally a possibility that both techniques are used at the same period, the Mixed Tuna System: in that case the cheapest technique earns the majority of the rent. Hence there is a possibility that the Farmed Tuna Method captures the majority of the labor rent if the method is cheaper than the Wild Tuna Method.

In all cases, the wage is given by:

$$w = \frac{b_{11} - (1 + r)\, a_{11}}{l_1} \tag{4.83}$$

If we observe a Wild Tuna System, the price of tuna is then:

$$p^W_{2,t} = \frac{1}{b_{22,t}} \left[(1+r)\,a_{21} + \frac{b_{11} - (1+r)\,a_{11}}{l_1} \right] \tag{4.84}$$

If we observe a Farmed Tuna System, the price of tuna is:

$$p^F_{2,t} = \frac{1}{b_{32} - (1+r)\,a_{32}} \left[(1+r)\,a_{31} + \frac{b_{11} - (1+r)\,a_{11}}{l_1} \right] \tag{4.85}$$

Finally if we observe a Mixed Tuna System, we have two equations (4.81 and 4.87) with two unknowns ($p_{2,t}$ and z_t). This can be solved:

$$\rho_t = \frac{b_{22,t}\left[(1+r)\,a_{31} + w\right] - \left[(1+r)\,a_{21} + w\right]\left[b_{32} - (1+r)\,a_{32}\right]}{y_2\left[b_{32} - (1+r)\,a_{32}\right] - b_{22,t}y_3} \tag{4.86}$$

$$p^M_{2,t} = \frac{(1+r)\,a_{21} + w + y_2\rho_t}{b_{22,t}} \tag{4.87}$$

If we want a positive rent and if $\frac{[b_{32}-(1+r)a_{32}]}{y_3} \geq \frac{b_{22,t}}{y_2}$, i.e. if the Farmed Tuna Method is more productive than the Wild Tuna Method, then we need that $\frac{[(1+r)a_{31}+l_3w]}{[b_{32}-(1+r)a_{32}]} \geq \frac{[(1+r)a_{21}+w]}{b_{22,t}}$, i.e. we need that the input costs per unit of output are higher in the Farmed Tuna Method (this is coherent with the way Sraffa describes intensive rent, Sraffa, 1960, § 87). If these conditions hold, the derived function of the rent ρ_t along $b_{22,t}$ being positive, the rent will then increase if the population of tuna is increasing. Similarly we can see that if the activity level of the Wild Tuna Method increases, the rent goes down and if the activity level of the Farmed Tuna Method increases, the rent goes up.

4.4.3.3 A numerical example

Now let's have a numerical example.

Table 4.5: Processes in the simple Corn-Tuna Model - numerical example (simplification from Erreygers, 2014)

Inputs				Outputs	
Corn	Tuna	Labor		Corn	Tuna
2	0	1	$\rightarrow$	10	0
1	0	1	$\rightarrow$	0	$b_{22,t}\,(P_t)$
1	1	1	$\rightarrow$	0	10

Wage is now always equal to:

$$w = 8 - 2r \tag{4.88}$$

If we observe a Wild Tuna System, the price of tuna is:

$$p_{2,t}^{W} = \frac{9-r}{b_{22,t}} \tag{4.89}$$

If we observe a Farmed Tuna System, the price of tuna is:

$$p_{2,t}^{F} = 1 \tag{4.90}$$

Finally if we observe a Mixed Tuna System, the price of tuna and the rent are:

$$\rho_t = \frac{(b_{22,t} - 9 + r)(9-r)}{y_2 (9-r) - y_3 b_{22,t}} \tag{4.91}$$

$$p_{2,t}^{M} = \frac{9 - r + y_2 \rho_t}{b_{22,t}} \tag{4.92}$$

These results depend on the catch function. Suppose that we have $k_1 = 1/100000$ and $k_2 = 1/1000$, with a maximum population of $L = 20000$. The average catch per worker is then $b_{22,t} = P_t/1000$. If the Wild Tuna Method is therefore used, and if the tuna population is decreasing, the catch per fisherman will decrease and the price of tuna will increase. Neither there are Hotelling's rule nor equilibrium involved, this is just a technical relationship between the physical data.

There are then two possibilities:

1. Either the level of activity y_2 is at such level that the catch is below or equal to the sustainable catch $c_t^* = P_t (20000 - P_t)/100000$. For instance, if $P_t = 15000$, we have $c_t^* = 750$. The maximum activity level is then $y_2 = c_t^*/b_{22,t} = 50$. If the amount of fisherman is equal or lower than 50, the resource is renewable. As an example, if the amount of fisherman is $y_2 = 30$, in the next period, population of tuna will be equal to $P_{t+1} = P_t + k_1 P_t (L - P_t) - y_2 k_2 P_t = 15300$. If the Wild Tuna Method is the only method used, with constant level of activities and a constant rate of profit, the price of tuna will be lower in the next period. For instance, with $r = 10/100$, we have $p_{2,t}^{W} = 89/150 \sim 0.59$ and $p_{2,t+1}^{W} = 89/153 \sim 0.58$. If we observe a Mixed Tuna System, the rent counterbalances the decrease of the price. If $y_3 = 1$, we have $\rho_t = 5429/25200 \sim 0.22$ and $\rho_{t+1} = 5696/25170 \sim 0.23$ and the price of tuna increases slightly: $p_{2,t}^{M} = 2581/2520 \sim 1.024$ and $p_{2,t+1}^{M} = 43877/42789 \sim 1.025$. This movement of population, price and rent will come to an end when the population reaches its maximum level, i.e. when $P_\infty = L$. The price of tuna will then be in the Wild Tuna System equal to: $p_{2,\infty}^{W} = 89/200 = 0.445$ and in the Mixed Tuna System the rent will be equal to $\rho_\infty \sim 0.4$ and the price of tuna equal to $p_{2,\infty}^{M} \sim 1.045$.

2. Or the level of activity is unsustainable, i.e. higher than the sustainable one. As an example, with $P_t = 15000$, the catch is set to $c_t = 1500$. The activity level is then $y_2 = c_t/b_{22,t} = 100$ and in the next period,

population of tuna will decrease to $P_{t+1} = 14250$. If the Wild Tuna Method is the only method used, all other things being constant, the price of tuna will be higher in the next period. For example, with $r = 10/100$, we have $p^W_{2,t} = 89/150 \sim 0.59$ and $p^W_{2,t+1} = 890/1425 \sim 0.62$. If we observe a Mixed Tuna System, the rent counterbalances the increase of the price. If $y_3 = 1$, we have $\rho_t = 5429/87500 \sim 0.06$ and $\rho_{t+1} = 9523/175150 \sim 0.05$ and the price of tuna slightly decreases: $p^M_{2,t} = 8811/8750 \sim 1.007$ and $p^M_{2,t+1} = 334818/332785 \sim 1.006$. This movement of population, prices and rent will come to an end if the increase of the population becomes equal to the catch, i.e. when $k_1 P_t (L - P_t) = y_2 k_2 P_t$. In our case, the population will decrease until $P = L/2$, and then will be kept at this level. At this level the price of tuna will be in the Wild Tuna System equal to: $p^W_{2,\infty} = 89/100$; in the Mixed Tuna System the rent will be equal to $\rho_\infty \sim 0.011$ and the tuna price equal to $p^M_{2,\infty} \sim 1.001$. But there is the possibility that the number of fishermen is so high that the increase of tuna population will never be equal to the catch: this occurs when $y_2 \geq 200$. In this case, the population will decrease until there is no more tuna in the sea. However, as it will be harder and harder to find it, the Farmed Tuna Method will become more and more profitable: and at one level of population the rent becomes equal to zero, and then becomes negative when the majority of the rent is won by the Farmed Tuna Method. This turning point occurs when the price of the Wild Tuna becomes equal to the price of the Farmed Tuna, i.e. in our case when $b_{22,t} = 9 - r$; the population level at the turning point is equal to: $P_t = \frac{9-r}{k_2} = 8900$.

Chapter 5

SRAFFA: an inspiration for Ecological Economics?

References to Sraffa and to the neo-Ricardian school is something quite customary in ecological economics. By looking at contributions in ecological economics (since the beginning of this field) which deal with the neo-Ricardian methodology, we see that a connection between both schools still has to be made. This connection should be articulated around the initial aim of Sraffa: to develop a new paradigm, competing against the neoclassical one. Only then it will be possible to develop a real eco-Sraffian approach able to pursue the analysis of the sustainability of the economic system.

This chapter is divided into three sections which describe, in detail, the works of the main authors talking about the links that can be made between ecological economics and Sraffa. Section 5.1 describes the part of the literature engaged in the "valuation of nature" debate; section 5.2 the works of researchers attempting to develop a neo-Ricardian approach of ecological conflicts. In each of these sections, works are presented in a (more or less) chronological way. In section 5.3, we present two types of works: the firsts deal with the concept of rent (absolute and differential), the seconds try to use the neo-Ricardian knowledge in the analysis of physical interdependence between processes, in particular for the assessment of CO_2 emissions.

5.1 The first direction: monetary valuation of the environment, energy theory of value

5.1.1 Georgescu-Roegen

The debate about the valuation of ecosystem resources and services is a very old one. In an interview with Pellegrini (2012), Martinez-Alier underlines that we can find its beginning in the debate between Wilhelm Ostwald (1908)[1] and Alfred Weber (1909) in the beginning of the XX$^{\text{th}}$ century. Ostswald is one of the first to argue that a strong relationship exists between the use of energy and economic growth. However, from that, he does not deduce any theory of value and explicitly warns that this would be impossible: "we would err if we measured value only in proportion to the amount of free energy" (Ostwald, 1908, p. 164). Weber answers that the determinant of action at the micro-level is profitability, and not energy efficiency. This debate is carried on later by Neurath (1973), Von Mises and Hayek (1952). Neurath says that it is impossible to base decisions on prices about about the use, or not, of non renewable natural resources, as it is impossible to know their future utility for future generations, whereas for Von Mises, prices express rationality and help to ensure an efficient allocation of resources and consumption goods, even in an inter-temporal way. Hayek adds to Von Mises point of view a strong criticism of the social engineering of Saint Simon, but also of Neurath, because the rejection of prices as efficient indicators for the management of natural resources would lead to social planning of production, and thus, for Hayek, to dictatorship.[2]

This debate is then revive by the birth of what Georgescu-Roegen (1979) calls the new "energetics" dogma. Researchers such as Fred Cottrell (1953), H. T. Odum (1973; 1977; 1981), Harrison Brown (1954; 1957), Alvin Weinberg, Glenn Seaborg and, even if he relaxes his position later on, Kenneth Boulding (1966) believe that all physical exchanges can be reduced to energy exchange and that, if the input flow of energy is big enough, it would be possible to recycle all material flows inside the economy and effectively build a Space-ship Earth economy. From that, some of them (e.g. Gilliland, 1976; Slesser, 1975) say that an energy theory of value could be constructed where energy would be the economic unit of value (British thermal unit, BTU, for instance, instead of

[1] Ostwald was part of research group, including Ernest Solvay, George Helm, Pierre Duhem and Frederick Soddy (1926), deepening the works of Ernest Mach; for them, "matter must in the ultimate analysis reduce to the only 'substance', energy" (Georgescu-Roegen, 1979). They were one of the firsts to say that economy cannot violate thermodynamics laws.

[2] My point of view on this debate is that Weber is right when he says that the determinant of action at the micro-level is profitability; but at the macro-level, one of the consequences of economic growth is an increasing energy consumption (Ayres et al., 2013). Von Mises is right when he says that prices can help to allocate scarce resources, but only in situations with no uncertainty, no future generations and with a perfect and fair initial distribution of revenue. Finally Hayek is right to criticize the dictatorial vision of Saint Simon, but he is wrong if he thinks that the actions of free agents will always engender the optimal society. According to me, Ostwald and Neurath defend the right position that the economic way of assigning exchange values cannot work for the assessment of natural resources values.

dollars). Their point is that, if all physical exchanges can be reduced to energy exchanges, it could be possible to reduce also money exchanges. The efficiency of an economic system should then be measured by looking at the amount of energy needed to produce a given amount of money instead of looking at the amount of money produced per capital or per unit of labor.

However, to measure this efficiency one must account how much energy is needed by the system. And there arise some controversies about:

- should we take into account the energy consumed by human labor?

- should we take into account the amount of energy available outside the economic system (gross energy analysis, e.g in Cottrel, 1953; Odum, 1973)?

- or should we take into account only the amount of energy available in usable form for the economic system, i.e. after extraction (net energy analysis, e.g. in Chapman et al., 1974; Price, 1974; Slesser, 1977)?

This last proposal is thus concerned only about efficiency within the system, and not about the efficiency of the link between the environment and the economy, which is taken into account in the gross energy analysis. Apart from these questions, these researchers inside the new "energetics" dogma do not move away from the neoclassical paradigm as they think that utility (use value) can be measured on money terms (exchange value). They also ignore the warning given by Ostwald that energy cannot be the sole explanation of value.

Georgescu-Roegen strongly stand against the new "energetics" dogma, arguing that:

1. Energy matters but matter matters too, in two important ways. First it is not possible to create all materials from energy as only the big-bang created proton and neutron from energy alone : "certainly, we can also convert energy into additional mass, but only in very special cases (usually, in laboratory installation) and in relatively small amounts and not into *nucleon* mass" (Georgescu-Roegen, 1979). Second, matters, like energy, is continuously lost for human use : "all over the material world there is rubbing by friction, cracking and splitting by changes in temperature or evaporation, there is clogging of pipes and membranes, there is metal fatigue and spontaneous combustion" (Georgescu-Roegen, 1979). Both arguments explain why complete recycling of matter is not possible (Georgescu-Roegen calls this the Fourth Law of Thermodynamics or "Law of Matter Entropy"), and thus why the new "energetics" dogma is wrong: an economic system cannot but exchange energy *and matter* with the environment.[3]

[3]Cleveland and Ruth (1997) records some arguments against this Fourth Law. For instance, "well-documented counter examples to Georgescu-Roegen's Fourth Law include the biogeochemical cycles — driven by the influx of solar radiation — that constantly funnel dissipated materials through a closed, global ecosystem and temporarily generate high material concentrations. It is those processes that lead to the formation of pearls from ocean water in the first place, the agglomeration of metals in ores and the formation of fossil fuels" (Cleveland and Ruth, 1997). Cleveland and Ruth defend the Law by arguing that even if we can find some counter examples in nature, there is no counter example in a time frame relevant

2. Economy is not just about production of commodities, but also about distribution of the surplus: this distribution influence the economic value of commodities. But the issue of distribution cannot be tackled by an energy theory of value (or an "energy+matter" theory of value). To explain this point Georgescu-Roegen constructs a simplified flow-fund economic system. Flows are the exchanges of energy and materials between industries. Funds are "the agents that performed the change" (Georgescu-Roegen, 1979): these agents are human labor, capital and land. Funds must be represented because "in any economic system both the quantities represented by the flow elements *and* the services provided by the agents have value" (Georgescu-Roegen, 1979).[4] And this is the main difference with economic systems constructed by the partisans of the new "energetics" dogma. In their models, only exchanges of energy (and/or matter) are represented. Hence services provided by the agents have no value, apart from the energy spent producing this service. The political struggle about the value of services such as human labor or capital and land loans is not then represented and the distribution of the surplus have no influence on the energy price.

Let us describe this flow-fund economic model where, as a starting hypothesis, Georgescu-Roegen assumes that only energy is exchanged with the environment. There are five economic processes: process 1 creates controlled energy (ce), material waste (w) and dissipated energy (d) from capital (k) and energy in situ (es); process 2 creates capital, material waste and dissipated energy from controlled energy and recycled matter (rm); process 3 creates consumption goods (c), material waste and dissipated energy from controlled energy, capital and recycled matter; process 4 creates recycled matter and dissipated energy from controlled energy and capital; and finally process 5 is the process of consumption, creating only material waste and dissipated energy from controlled energy and capital. All processes are using furthermore the stocks of Capital Equipment (K), People (H) and Ricardian Land (L).

The model can be represented like this, with **A** the input matrix and **B** the output matrix, processes in column and resources in row:

to the human economy: "biological systems ... differ markedly from economic systems with regard to the time available to trace, collect and upgrade materials. Ore deposits and fossil fuels have been formed over time periods that are far too long to be of relevance for economic decision making. ... hence, from an economic perspective, an increasing dispersal of materials is constraining as long as tracing, collecting and upgrading those materials requires expenditures of finite, costly sources of low-entropy energy" (Cleveland and Ruth, 1997).

[4] Here I disagree with Georgescu-Roegen: services provided by the agents (i.e. "funds" for Georgescu-Roegen) have value (and thus influence the value of all goods) because the agents *claims that they have value*. They do not have value by themselves, there is no intrinsic value of such services: we could imagine an economic system where some funds have no value (land for example, or human labor in case of slavery).

$$\mathbf{A} = \begin{bmatrix} 0 & ce_2 & ce_3 & ce_4 \\ k_1 & 0 & k_3 & k_4 \\ 0 & 0 & 0 & 0 \\ 0 & rm_2 & rm_3 & 0 \end{bmatrix} \tag{5.1}$$

$$\mathbf{B} = \begin{bmatrix} ce & 0 & 0 & 0 \\ 0 & k & 0 & 0 \\ 0 & 0 & c & 0 \\ 0 & 0 & 0 & rm \end{bmatrix} \tag{5.2}$$

The inputs of the production process are represented in the column vector $\mathbf{c}$:

$$\mathbf{c} = \begin{bmatrix} ce_5 \\ k_5 \\ c_5 \\ 0 \end{bmatrix} \tag{5.3}$$

The production of material waste is represented by the row vector $\mathbf{w}$:

$$\mathbf{w} = \begin{bmatrix} w_1 & w_2 & w_3 & 0 & w_5 \end{bmatrix} \tag{5.4}$$

The production of dissipated energy is represented by the row vector $\mathbf{d}$:

$$\mathbf{d} = \begin{bmatrix} d_1 & d_2 & d_3 & d_4 & d_5 \end{bmatrix} \tag{5.5}$$

The inputs of energy in situ is represented by the row vector $\mathbf{es}$:

$$\mathbf{es} = \begin{bmatrix} es_1 & 0 & 0 & 0 \end{bmatrix} \tag{5.6}$$

The funds of Capital, People and Land are represented by the row vectors $\mathbf{k}$, $\mathbf{h}$ and $\mathbf{l}$:

$$\mathbf{k} = \begin{bmatrix} K_1 & K_2 & K_3 & K_4 \end{bmatrix} \tag{5.7}$$

$$\mathbf{h} = \begin{bmatrix} H_1 & H_2 & H_3 & H_4 \end{bmatrix} \tag{5.8}$$

$$\mathbf{l} = \begin{bmatrix} L_1 & L_2 & L_3 & L_4 \end{bmatrix} \tag{5.9}$$

Starting with net energy analysis, Georgescu-Roegen tries to find a definition for net energy : "Four possible definitions of net energy seem to deserve attention: a) [ce]; b) the difference between [ce] and the energy equivalent of [k_1]; c) [ce_5]; and d) [ce_5] plus the energy equivalent of [k_5] and [c_5]" (Georgescu-Roegen, 1979). Definitions a) and c) are discarded and definitions b) and d) lead to the same result. Defining e_i as the "energy equivalent per unit of flow product" of resource i and $\mathbf{e}$ the row vector with all e_i as components, we can find the Net Energy NE by solving the following system of equations:

$$\mathbf{eB} = \mathbf{eA} + \left[\begin{array}{cccc} NE & 0 & 0 & 0 \end{array} \right] \tag{5.10}$$

If we state that the energy equivalent per unit of flow product of controlled energy is equal to one, energy becomes the numeraire of the system. Georgescu-Roegen notes that if the material waste is to be accounted, through energy equivalence, as a joint product in each process, the system of energy price becomes undetermined (as there are more resources than processes).

Georgescu-Roegen then looks at the gross energy analysis: here the system of energy price (with a new vector $\mathbf{e}'$) becomes:

$$\mathbf{e}'\mathbf{B} = \mathbf{e}'\mathbf{A} + \mathbf{es} \tag{5.11}$$

The two systems 5.10 and 5.11 are thus closely related. The numeraire in the second system is given by the unit in which energy in situ is measured. Hence the relation between both system is simply:

$$NE = \frac{es_1}{e'_1} \tag{5.12}$$

In both cases, the surplus is converted into energy equivalent, and then distributed to the owner of the energy in situ.

Turning to economic valuation, Georgescu-Roegen then says that services, arising from the stocks, influence values. The system of prices is then:

$$\mathbf{pA} = \mathbf{pB} + p_K\mathbf{k} + p_H\mathbf{h} + p_L\mathbf{l} \tag{5.13}$$

Georgescu-Roegen further adds “the equation of the national budget”:

$$\mathbf{pc} = [p_K\mathbf{k} + p_H\mathbf{h} + p_L\mathbf{l}] \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \tag{5.14}$$

Thus there is no proportionality between the energy system of value and the economic system of value, unless two of the three distributional variables p_K, p_H and p_L are set to zero. And Mayumi (2001, p.71)[5] furthermore shows that, if we have a rent R on energy in situ, there is no proportionality as soon as one distributional variable is different from zero, because the system of price becomes:

$$\mathbf{pA} = \mathbf{pB} + R\mathbf{es} + p_K\mathbf{k} + p_H\mathbf{h} + p_L\mathbf{l} \tag{5.15}$$

[5] Mayumi looks at empirical applications of the flow-fund model of Georgescu-Roegen and in order to do that, he develops the Multi-Scale Integrated Analysis of Societal Metabolism (MSIASM, Gowdy et al., 2009). The goal is to look at societies through the lens of their use of human labor and exogenous energy. These two inputs are considered as “primary inputs”, but the human labor is seen as a fund, thus “requiring investment at reproduction” (Gowdy et al., 2009). Indexes such as “the saturation index of human labor” can be deduced, at the national or sectoral level.

Mayumi also compares Georgescu-Roegen's and Sraffa's models (Mayumi, 2001, p.71-72, Mayumi and Tanikawa, 2012). There are two main differences:

- fixed capital is a fund for Georgescu-Roegen, which depreciates and is nourished by a single process (at each period the value of the capital produced is equal to $p_2 k$, and this value is equal to the depreciation of capital if we are in a stationary state) whereas it is a set of different commodities for Sraffa (machines with different ages are different commodities).
- The profit is seen as a rent on capital, in order to pay for the service of the capital fund, whereas in Sraffa the profit is a rate of return for a process (there is no payment for any "service", the origin of profit lies in the production of a surplus, and in the claim for a part of this surplus from the capitalists).

5.1.2 Costanza

Costanza (1980; 1981) looks at the relation between the economy and the environment from the point of view of "energy-value". He constructs a model designed to compute the costs of the production of each good in terms of solar energy (which he calls embodied solar energy). From this, he wants explicitly to compute prices of natural resources.

He chooses a joint production system with m processes and n goods, defined by the following value system:

$$\mathbf{E} + \mathbf{e}\,\mathbf{A} = \mathbf{e}\,\mathbf{B} \tag{5.16}$$

With $\mathbf{A}$ and $\mathbf{B}$ $n \times m$ matrices of constant technical coefficients corresponding respectively to the inputs and the outputs,$\mathbf{E}$ the m line vector of direct solar energy inputs and $\mathbf{e}$ the n line vector of prices in terms of energy-value. If $m = n$, we can solve the system :

$$\mathbf{e} = \mathbf{E}\,(\mathbf{B} - \mathbf{A})^{-1} \tag{5.17}$$

We can see that we have an analogy with Sraffa's system when $w = 1$ and $\pi = 0$. The problem is that Costanza's system does not always compute only positive prices: in single production systems, the only positive coefficients of matrix $\mathbf{B} - \mathbf{A}$ are on the main diagonal, and this is why the inverse matrix is always positive. In joint production systems, we can found positive coefficients aside from the main diagonal.

In a following model, Costanza and Neill (1984) adopt a linear programming point of view. They assume that ecosystems want to maximize their surplus, valued in terms of energy-price:

$$\mathbf{eY} \tag{5.18}$$

With $\mathbf{Y}$ the vector of net exports, given in an exogenous way and expressed in physical quantities, knowing that :

$$\mathbf{e}\,(\mathbf{B}-\mathbf{A}) \leq \mathbf{E} \tag{5.19}$$

$$\mathbf{e} \geq \mathbf{0} \tag{5.20}$$

The initial available energy ($\mathbf{E}$) is given in an exogenous way (as are given initial quantities $\bar{\mathbf{Q}}$ in this kind of neoclassical systems), energy-prices ($\mathbf{e}$) represents scarcity indexes (like rent-prices $\mathbf{r}$) in relation to an exogenous demand ($\mathbf{Y}$) (equivalent to demand $\bar{\mathbf{p}}$) and the goal of revenue maximization allows the choice of the best available techniques. This model is applied for an ecosystem without any economic process.

However, soon thereafter, Costanza and Hannon (1989) go back to a system where economic and environmental processes are interdependent, with again equation 5.16. They draw an analogy between economic and ecological systems to justify the fact that prices are unique for each good within the system, saying that ecosystems reacts as if they were in a state of perfect competition:

> "for a system to be competitive in this sense, it must have many, small consumers and producers each possessing all the current information about the variables which affect them. Under these conditions, no single consumer can directly affect the unit weight of a commodity" (Costanza and Hannon, 1989).

Again negative values can then appear because of joint production, but "these negative intensities are most likely the result of poor data or poor system specification, and can be eliminated by better data or better specification of the system" (Costanza and Hannon, 1989).

They furthermore come up with the question of the value system if more than one net input is found:

> "consider an ecosystem with boundaries defined such that there are net inputs of both sunlight and water. In such a case we would calculate sunlight intensities and water intensities but we would have no way of comparing or adding the two" (Costanza and Hannon, 1989).

They accordingly choose to consider the largest system possible, Earth, where the only net input is solar energy. They are then able to compute the energy-price of one liter of water and of one dollar of manufactured product.

Some questions immediately appears:

1. Why is Costanza interested in an energy theory of value?

2. How and why can we compare two systems of value - energy value and economic value?

5.1.2.1 Why an energy theory of value?

Energy value is justified by Costanza because "the earth's hydrologic, geologic and nutrient cycles, and net primary productivity all depend on the planet's only significant net input - solar energy - to drive them" (Costanza and Neill, 1981); thus, energy-price is a measure of the dependence for each good on the initial energy input. According to Costanza, energy is a limiting factor, but in the same time a determinant for action: "available energy both limits and governs the structure of humans economy" (Costanza, 1980). By comparing the cost of production of one dollar in terms of energy for different sectors of the American economy, he shows that this cost is approximately constant: then he deduces that economic value is correlated with energy consumption. In fact, he shows that factors of productions (labor, capital, earth, energy) are interdependent and complementary: we cannot create value without energy, there could not be any substitution between, for instance, capital and energy.

This is a discredit for the neoclassical theory of value, which asserts that prices are determined by the market: here, values can directly springs from the methods of production, once the factor of proportionality between energy and dollar value is known. Market prices seems to gravitate around predefined values, which depend on the energy needed for the production, in the theory of Costanza. He even makes a clear parallel between his theory and the labor theory of value:

> "The question might be asked whether the same thing we have done with energy could not be done with any of the other currently defined primary factors and thus support capital, labor, or government services theories of value. The answer is that on paper this could be done. We must look to physical reality to determine which factors are net inputs and which are internal transactions. No one would seriously suggest that labor creates sunlight" (Costanza, 1980).

Curiously, he therefore empirically proves that the cost of production theory is correct, but nevertheless sticks to the utility theory to explain market prices. This can only be logical if utility itself is reduced into a quantity of energy (Burkett, 2006, p. 40). Nevertheless, he does not seems to see the conflict with the neoclassical theory of value: "there is no inherent conflict between an embodied energy (or energy cost) theory of value and value theories based on utility" (Costanza, 1980).

5.1.2.2 Comparing 2 systems of value

What can we learn with energy values? Costanza explains that it would be interesting to give a quantitative value to nature: "the potential utility to environmental managers and decision makers of defendable answers to questions like: what is the true extra-market value of rainfall? or ecosystem services? or non-renewable resources? is enormous" (Costanza and Neill, 1981).

How is this quantitative analysis built in Costanza? From an Input-Output table with the yearly flows of environmental resources (biomass, nitrogen, carbon dioxide, phosphorus, water vapor, liquid water, fossil energy), he deduces their energy prices, or their solar energy costs of production. In the table, two processes are economic ones : agricultural production, with an output measured in mass, and economic production, with an output measured in GNP, i.e. in dollars. He can then compute the price of the production of one dollar in terms of energy, and he can go backward to compute the price in dollar of all natural resources.

For instance, he can compare the energy price of gram pound of natural products and the energy-price of one dollar: $\frac{energy-price_{agri}}{energy-price_{dollar}} = \frac{39{,}2}{191{,}2} = 0,2$. We get an exchange ratio between these two goods, in terms of energy cost of production: production of 0.2 dollars costs as much energy as the production of one gram of natural products. And we can reverse it: the production of 5 grams of natural products cost the same amount of energy as the production of one dollar. The dollar is in this system equivalent to the gram unit, i.e. equivalent to a *physical* unit. We can exchange the quantity *one dollar* with the physical quantity *5 grams of agricultural products*. And we can do the same for all other natural resources. The problem with this is that if the energy efficiency of the production of one dollar increase, the "true extra-market value" of natural resources will increase: one dollar will be exchanged with less than 5 grams of agricultural product. The more we are independent from solar energy, the more natural resources become costly. This appears to be a clear contradiction with the neoclassical belief that if an input is less used, its value will decrease.[6]

What means the "true extra-market value" for Costanza is unclear. The important thing to remember is that, in this kind of analysis, value is related to the energy needed for production. The relative value of the environment depends on the proportion between its energy consumption and the energy consumption of the economy. This value does not express the relative impor-

[6] We can model the cohabitation in the system of Costanza (1981; 1989) of dollar-prices and energy-prices in the following way:

$$\mathbf{E} + \mathbf{e}\,\mathbf{A} = \mathbf{e}\,(\mathbf{D_p B}) \tag{5.21}$$

With $\mathbf{D_p}$ the diagonal matrix containing in his main diagonal prices $p_{ii} > 0,\ i = 1, \dots k$ in dollars for en dollar for economic resources and prices $p_{ii} = 1,\ i = k+1, \dots n$ for natural resources. Thus energy prices depends on the system considered, and this system (the coefficients of production) change when the value in dollar of economic goods change (when $\mathbf{D_p}$ change).

Costanza does not initially want to work with dollar values:

> "physical flow I-O data would be preferred for embodied energy calculations, but are not available in the required form at the national level. Calculations made with financial data are nevertheless useful, because they yield information on the direct and indirect energy required to produce a dollar's worth of each of the commodities in the economy" (Costanza, 1980).

But what would have happened if embodied energy data are found for all economic commodities? He would still have compared the energy required to produced one dollar, for each economic commodity.

tance of one resource upon an other for the production of economic value: if one natural resource is basic, its importance for the system is infinite.

5.1.3 Christensen

Christensen (1987) thinks that "the negentropic material and energy flows from geological and biological production systems [...] are the true 'basics' of economic activity". He wants to build a physical theory of production and thinks that the beginning of it can be found in the Classical theory, and particularly in Sraffa's analysis. However, he complains that, in those theories, energy is not taken into account and that there is not enough focus on material and energy constraints:

> "Sraffa (1960) contrasted Quesnay's (and the classicals') 'picture of the system of production and consumption as a circular process' with 'the view presented by modern (neoclassical) theory of a one-way avenue that leads from 'Factors of production' to 'Consumption goods" (p. 93). The entropic character of resource use suggests that each of these pictures is incomplete. Dissipation of available energy imposes a one-way direction on processes that otherwise have the character of circular pathways or loops" (Christensen, 1987).

In a second article Christensen (1989), Christensen starts by criticizing the widening gap between reality and economic thinking: economists do not pay attention to economic facts. He wants to add facts and theories from "physics, chemistry, biology and ecology" in order to build "the biophysical foundations of economic activity". A switch from physical facts to abstract theory and "analytical mechanics" can be seen as early as in Ricardo's works on land, "which is expressly defined as a factor immune to any qualitative change (which) we could refer to simply as space" (Georgescu-Roegen, 1971, cited in Christensen, 1989). At least Sraffa's model seems to have biophysical foundations, because there is the need of at least one basic commodity, which could be raw materials and food, to run the model.[7] Furthermore Christensen argues that the neo-Ricardian theory is interesting because prices are "reproduction prices", i.e. "they are formulated to ensure the replication of the components of the social-economic system through time".[8] But in this theory, there is no valuation of the environment: Christensen suggests that reproduction prices could apply also to environmental resources and services. And Christensen complains that material and energy balances are not introduced:

> "I first realised the need to apply the principles of the conservation of matter and energy to production and the entropy law in the

[7] Sraffa actually does not say anything about the nature of his basic commodities.

[8] Actually Sraffian prices do not ensure anything. Prices express the exchange ratios that would ensure the same production for the next period, but nothing ensure that the required exchanges will occur. Furthermore, prices are concerned with produced commodities: they may not take into account important components for the sustainability of the system, such as the availability of natural resources.

> April of 1976 when I was completing my dissertation and realised that Sraffa's production system lacked any physical specification of the material and energy flows required to produce commodities. A closed production system cannot reproduce itself" (Christensen, 2005).

But his main criticism goes against the neoclassical framework, as it focuses less on the condition of production, and more on exchange optimization. Thus the whole neoclassical theory of value becomes to contradict physical facts. For instance the notion of marginal productivity is in conflict with the way real system of production operates: there is strong interdependence between factors of production rather than independent productivity for each of them:

> "the notion of marginal productivity adopted by the early neoclassicals violates the fundamental scientific principles governing material and energy transformations ... The founding proposition of neoclassical economics, the principle of marginal productivity, is inconsistent with a scientific understanding of physical processes. And, as Schumpeter, Hicks and others have noted, without marginal productivity, there is no neoclassical theory" (Christensen, 2005).

All the early neoclassical authors (Jevons, 1871; Menger, 1871; Walras, 1874; Marshall, 1890) thinks in terms of substitution between factors of production, without paying attention about complementarities and mass and energy balances. They have been misleading by the Ricardian treatment of land, where an increase of the labor input alone could lead to an increase of production. However, this is actually only possible because some inputs (energy and materials) are not taken into account: in the real world, when the use of one input is increased, the output is not always increased, so marginal productivities cannot always be calculated. This mistake leads to the affirmation that distribution should be related to marginal productivity of only a few primary factors which can be substituted without constraint (e.g. in Wicksteed, 1894).

The neoclassical theory of price can then be relaxed from the observation of natural resource stocks and flows, technology development and constraints, etc., and concentrate only on initial endowments and consumers preferences. But, for Christensen, consumers preferences are not a good way to price natural resources:

> "since there is no way of discerning the preferences of unborn generations, this leaves us with the dictates of the market and the subjective judgments of the present generation as to the values which should be placed on resources and natural environments" (Christensen, 1989).

Behind his critique of the neoclassical theory of value, his goal therefore appears: he wants to put a value on the environment so that its use can be decided. He acknowledges that prices cannot be a guide for taking care of the natural resource (because of "uncertainty about future demand (including those of future generations), technological change, size of resource stocks, and rates of depletion coupled with discounting of the future", Christensen, 1987). However, his solution is to have a better understanding of the physical relation between the economy and the environment in order to extend "the range and content of prices (the market solution to environmental 'externalities')" (Christensen, 1987). However, this pricing will not be sufficient to ensure "the long-term viability of the environmental-economic system" (Christensen, 1989): there will be a need for an other regulation than market regulation alone (norm, law, quota, etc.).

This is why he needs a bio-physical approach to production. He starts from the Classical principle that value comes from production, and he adds to that "the low-entropy energy and materials extracted from the environmental systems and eventually returned as waste" (Christensen, 1989)[9] and also the flows of information: following Boulding (1978), he claims that the three factors of production are materials, energy and know-how. The economy can then be viewed as a set of chemical processes, or as an open thermodynamic system with solar energy as the sole input (as in Costanza, 1980). Inputs are complementary, as well as sectors of production: there is co-evolution between technologies as well as between the environment and the economy (Norgaard, 1988). On the same ground, time and geographic constraints should be reintroduced: production is a dynamic process, from extraction of natural resources to production of consumption goods, and each phase takes place and is influenced by a definite site. Novelty in techniques as well as change in demand should be introduced. Limits to growth can be traced back to the availability of natural resource and energy and to the availability of techniques of production.

As regards the pricing system, Christensen (2005) is close to the post-Keynesian theory of production:[10] in some post-Keynesian works (Kaldor, 1979), a distinction is made on the pricing of raw materials, subject to the law of supply and demand, and the pricing of industry goods, subject to price-cost pricing (or full-cost pricing, or again mark-up pricing - prices depends on the prices of the inputs and on the mark-up, or profits, that are expected and that can be different within industries). Christensen agrees with this and argues that for extractive industries "Under conditions of low demand, lowest cost producers may still be able to produce at a profit or even earn economic rents. But low prices dissuade new exploration and investment (setting the stage for a future escalation of prices as demand is restored). Increased demand and

[9]He does not explain if it is after or before extraction that natural resources should be taken into account.

[10]Post-Keynesian theory are mainly interested in growth dynamics, asking the question: "How does growth come about in a capitalist economy?" (Kronenberg, 2010). Their empirical penchant leads Post-Keynesian economics to reject the neoclassical explanation of production and distribution (rejection of aggregate production functions and of the general equilibrium theory), but they have never really been interested into environmental questions (part of the reasons are explained in Mearman, 2005). Nevertheless, there have been some attempts to connect ecological economics and post-Keynesian economics as they seem to be complementary approaches (see Kronenberg, 2010).

higher prices permit production from high-cost sites". He then explains that there is a connection between the price of primary commodities and growth, as shown by the work of Hamilton with oil, for example (Hamilton, 1983).[11]

I disagrees with Christensen on two points. First, Christensen overlooks the point that Classical economists were thinking in these terms: who should get a return on the produced added value? The central question was for them distribution, not the physical limits of production. For instance, Christensen disagrees with Stuart Mill (1848b) when the latter discards the distinction between energy and materials, and put them in the same heading, "materials" (Mill had a discussion on this point with Senior, 1848, who was more willing to make this distinction because energy is not embodied into the produced good, as opposed to materials). There was no reason for Mill to make such distinction, as he was thinking in terms of political economy. According to Christensen, this was a mistake because himself is thinking in terms of energy and material balances. However, he wants to look at the connection between the consumption of material and energy and the production of wealth, whereas Mill wonders who produces the wealth and how the distribution of wealth is achieved.

Sraffa also was not focusing on the feasibility of the physical loop, but on the value created by the system of production. The question Sraffa attempts to answer is: can we determine the exchange relations (price) with just data about inputs and outputs? Here there are two possibilities: or we assume that only marketed goods enters into the equations (Sraffa explicitly says that he was concerned about commodities sold on the market), or we assume that, as Sraffa does not want to introduce demand in his model, he does not know what produced commodity is a good or a bad (but actually Sraffa never says that demand was not included in his model, cf. Sinha, 2007). My position is that Sraffa's prices express the exchanges needed to reproduce the system. But this reproduction may not occur in reality as the only exchanges taken into account are exchanges of marketed commodities and services: of course the economic system is an open one, with wastes rejection and natural resources extraction. However, they do not necessarily have a price, because they are not marketed commodities. They could, a rent can be stated on a land, and a tax can be asked for each waste disposal: only then they can be accounted in Sraffa's model.

The second point I disagree with Christensen is about the pricing system in the case of the extractive industries. My position is that prices rise when demand rise because more costly sites have been putted on production: I reverse the causality of Christensen reasoning. There is then no need to make a distinction in the system of production between extractive industries and other industries. However, it is likely that, due to political and financial reasons, the real market prices of raw materials will differ from their Sraffian prices.

[11]And current neoclassical models cannot explain why elasticity between oil and growth is so high: elasticity found in these models is around 10%, but in reality it is more around 60% (see Giraud, 2014 on this point).

5.1.4 Judson

Judson (1989) explicitly calls for a rapprochement between Sraffian and ecological economists, because they share the same theory of value. According to him a theory of value must specify:

1. the scale of the analysis: micro in the case of the utility theory of value, macro in the case of the labor theory of value. According to Judson, the two scales and the two systems of value can co-exist: "if one can sum all of the inputs into a commodity, its value can be determined independent of subjective preferences. This value operates as a 'center of gravity' for a commodity's price, around which its price will oscillate due to short term conditions" (Judson, 1989).[12]

2. the objectivity of the analysis: subjective in the case of the utility theory of value, depending on individual preferences, whereas the labor theory of value is said to be "independent of exchangers' preferences", and thus more objective.[13]

3. the role of time into the analysis: marginal analysis in the utility theory of value is usually static (demand and quantities are initially given) whereas the labor theory of value is said to allow a dynamic analysis (proportional dynamics for instance).

Judson adds : "neo-Ricardian's began to challenge the Marxian analysis, arguing that labor (the Marxian basis for commodity value) is only one of the many inputs into the production of commodities" (Judson, 1989).[14] On the same footing, Judson challenges the energy theory of Costanza: "Sraffa's commodities are valued interchangeably with one another, while Costanza 'carries back' the costs into their energy value" (Judson, 1989). He thus highlights the fact that other inputs than energy are equally important for the production of economic goods. He furthermore asserts that an energy theory of value is not sufficient to explain how the surplus is distributed. But rather than explaining the distribution of such surplus in a political way, he explains that the price

[12] He thus see the Sraffian analysis as an equilibrium theory, following Garegnani (1976) rather than Sinha (2012).

[13] On that point Judson says that labor value is the inherent value of a commodity: "if values inheres in objects in some operating way, then the ability of actors to modify the valuing structure is more limited" (Judson, 1989). I do not agree with Judson here, as I think that exchange value, even reduced to labor-value, is a value attached to a commodity by the specific system of production used to produce this commodity. Labor value is no more inherent than utility value, the first is attached by the system of production, the second by an individual.

[14] Again I do not agree with Judson: the neo-Ricardian theory does not contradict the fact that in a capitalist system of production, labor is the substance of the exchange value, as it is always possible to reduce "prices of every commodities into a sum of profit weighted quantities of labor" (Pasinetti, 1973), even in case of joint production. This is because labor is the sole non-produced input in Sraffa's system, and because all processes need labor as an input.

of non-basic commodities (and the rate of profits in these industries) are indeterminate and susceptible to "be better predicted by their position in actors' subjective preference schemes" (Judson, 1989).[15]

Judson divides the energy theory of value into three schools (Judson, 1989) :

- Energy-value of a commodity as the energy that the commodity can supply (the work of H.T. Odum is a good example, Odum and Odum, 1981). This vision is criticized by Georgescu-Roegen essentially because energy cannot substitutes matter (Georgescu-Roegen, 1979).
- Energy-value as the production cost of the commodity in terms of energy (Costanza, 1980; Costanza and Neill, 1981; Costanza and Hannon, 1989). This vision has been criticized by Daly (Daly, 1982) on the ground that the goal of the economy is not to maximize energy value, but utility value for consumers.
- Energy-value as an efficiency criteria to value ecosystems (Costanza and Neill, 1984): in this view, the goal of the ecological production is to produce the maximal surplus from an initially given amount of energy.

Instead of choosing one theory of value, Judson compares 2 systems of value: labor theory of value and energy theory of value, with energy as a cost of production. Elaborating on the work of Kregel (1973), he represents an economy with labor as the only mean of production:

$$\mathbf{p}\mathbf{q}_c = D = \mathbf{w}\left(\mathbf{n}_c + \mathbf{n}_i\right) \tag{5.22}$$

With $\mathbf{p}$ the line vector of consumption goods prices, $\mathbf{q}_c$ the column vector of consumption goods physical quantities, D the scalar of the demand for consumption goods, expressed in value, $\mathbf{w}$ the line vector with in each element the uniform wage w, $\mathbf{n}_c$ the column vector of labor quantities required in each sector to produce the consumption goods and $\mathbf{n}_i$ the same vector, but for investment goods.

If there is no investment, equation 5.22 becomes:

$$\mathbf{p}\mathbf{q}_c = \mathbf{w}\mathbf{n}_c \tag{5.23}$$

To produce the same physical quantity of consumption goods, Judson then introduces a need for energy:

$$\mathbf{e}\mathbf{q}_c = \mathbf{e}_\epsilon \epsilon + \mathbf{e}_\tau \tau \tag{5.24}$$

With $\mathbf{e}$ the line vector of the energy cost of production for each consumption good, ϵ the column vector of the physical quantities of raw materials needed to

[15] He actually seems to confuse to separate problems: the question of the distribution of the surplus (which can consist of basic and non-basic commodities) and the question of the value of non-basic commodities. While the first question is a political one, the second may be related with individual preferences.

be extracted, τ the column vector of the physical quantities of raw materials needed to be transformed into consumption goods and $\mathbf{e}_\epsilon$ and $\mathbf{e}_\tau$ the line vectors respectively of the energy needed to extract one unit of raw materials and of the energy needed to transform one unit of raw materials.

If labor is the only means of production and if there is no investment needed, equation 5.24 becomes:

$$\mathbf{e}\mathbf{q}_c = \mathbf{e}_i\mathbf{n}_c \tag{5.25}$$

With $\mathbf{e}_i$ the input of energy needed per unit of labor, each element being equal to e_i. Thus prices and energy prices becomes proportional:

$$\mathbf{p} = \frac{w}{e_i}\mathbf{e} \tag{5.26}$$

According to Judson, this proportionality changes as soon as investment goods, produced by labor, are reintroduced. This is because the sale of the consumption goods must be enough to cover the costs of both the production of consumption and the production of investment goods. The energy cost of production is not changed, but the cost of profit - needed to invest - must be added to the price equation. The new system is thus written as:

$$\begin{aligned} \mathbf{e}\mathbf{q}_c &= \mathbf{e}_i\mathbf{n}_c \\ \mathbf{p}\mathbf{q}_c &= \mathbf{w}\left(\mathbf{n}_c + \mathbf{n}_i\right) \end{aligned} \tag{5.27}$$

Equation 5.26 then becomes:

$$\mathbf{p} = \frac{\mathbf{w}\left(\mathbf{n}_c + \mathbf{n}_i\right)}{\mathbf{e}_i\mathbf{n}_c}\mathbf{e} \tag{5.28}$$

Hence the “energy buying power of money” has decreased, because of the need for investments; prices have rose, but energy consumed is the same (we could of course regret that energy is not needed to produce investment goods). Judson stops here his analysis: he does not go as far as Costanza, who reduces energy prices into monetary prices.[16]

[16] His article stops with some proposals of research questions that must be investigated by ecological economists as well as neo-Ricardians:

1. Following the work of Costanza (1980), investigation of the relation between energy cost and price, through Input-Output analysis, on the world or national level;
2. Study of the differences between energy qualities and their impacts on the energy theory of value;
3. Dynamic analysis of past and futures energy values;
4. Comparison of energy values in different countries;
5. Study of international exchanges under the light of the energy theory of value.

5.1.5 Ecological prices: Hannon

Hannon tries an original exercise: to define the value of human activities from the point of view of the Nature. He wants to construct an evaluation process independent on human decision, as "a useful compromise between the ecological purist, the intrinsic valuist and the neoclassical economist" (Hannon, 1998). However, the result is a bit disappointing: he computes ecological prices, in a way very similar to Costanza (Costanza, 1980; Costanza and Neill, 1981). While attempting to take the point of view of the nature, he assumes that "nature acts as though it is trying to maximize [its] net output" (Hannon recognizes that this assumption is "an obvious appeal for a sort of natural Aristotelian final cause"). Thus, if an activity destroys natural resources, its product is valued less than the product of an activity increasing nature net output.

He tries to justify this objective function of nature by saying that "even inanimate objects can be viewed as acting as though they have a purpose" (Hannon, 1998).[17] According to Hannon it should therefore be possible to deduce from the observation of natural processes an "ecological 'welfare function"', making the parallel with the neoclassical attempt to build a "Social Welfare function" by looking at "the utilities of all the actors in an economic system". But this parallel stops here, because Hannon adopts a macroeconomic point of view, looking at processes at a global scale, where neoclassical economists adopt an individualistic point of view. He finally justifies this "motivational assumption" by saying that if the goal of nature is to maximize its net output, then "the less the natural system deviates from such a path, the more stable it is, and the more we can depend on it" (Hannon, 1998). Thus for him nature should operate as an efficient process, because this serves human purposes.

As the net input of nature's system, he chooses "photosynthesized sunlight": this choice is made under the assumption that "it is the limiting input in the production of the net output. Otherwise, the net input would be set in terms of whatever the limiting input happens to be". A good question of course is: what if there are several limiting outputs? Then,

> "an economist would say they are differently priced factors of production. To group them into a single vector of net inputs requires the idea of relative value of the different net input forms. By asserting a production function for the system, one could find the marginal productivities of each of the inputs and sunlight. It is easy enough to show that the value ratios are the ratios of the marginal productivities" (Hannon, 1998).[18]

For the sake of simplicity, heat and water inputs, which are other possible limiting inputs, are assumed to be of zero value.

[17] I disagree with this: inanimate objects obey to physical laws. A purpose tries to answer a necessity, whereas a physical law is just the result of blind chance.

[18] This last sentence is not "easy enough" to accept, because this depends on the production function, and if all net inputs are limiting factors (or complementary inputs), a little increase of one input may not increase production outputs.

The value of the net input is equal to the value added, i.e.to the value of the net output of the system (unless we are in an open and dissipative system where the value of the output is less than the value of the input). Making reference to Samuelson (1966), he says that the only possibility to calculate positive prices from a system of process exchanges is when there is only one exogenous input (i.e. an input not produced by the system), single production and constant returns to scale (this last point is wrong, as Sraffa proves it, but neither Samuelson - see Sinha, 2007 - nor Solow, 2014, understood this). The ecological price system is then:

$$\mathbf{E} + \mathbf{e}\,\mathbf{A} = \mathbf{e}\,\mathbf{B} \tag{5.29}$$

Thus we obtain the same system as Costanza (1980; 1981). By adding human processes, Hannon expects to see whether the net output increases or decreases, thereby defining the value added of the human activity.

The goal behind this exercise is clear: “to elaborate a procedure that may be used to answer the natural system evaluation questions” and to raise a debate about how we “see ourselves as belonging to the living system, belonging to nature” (Hannon, 1998). This is an interesting point of view, because if we are a part of nature, then the procedure of valuation devised by Hannon is useless; and if we are not inside nature, how to differentiate natural processes from human processes? How to differentiate nature from artifice? Is there a difference (see the skepticism on that point from Clément Rosset, 1973)?

5.1.6 Neoclassical theory of value and ecological economics

A paper by Farber, Costanza and Wilson attempts to connect ecological economics and the neoclassical theory, by looking at the question of the valuation of environmental resources and services (Farber et al., 2002). According to them,

> “‘value systems’ refer to intrapsychic constellations of norms and precepts that guide human judgment and action. They refer to the normative and moral frameworks people use to assign importance and necessity to their beliefs and actions” (Farber et al., 2002).

They have therefore an individualistic starting point, looking at creation of value in someone’s mind, and not at the social level. Following that, they define value as “the contribution of an action or object to user-specified goals, objectives or conditions” (Farber et al., 2002). Value is therefore for them “use-value”, as it is attached to an object via a specific user. “Valuation” is defined as “the process of expressing a value for a particular action or object ... Ecosystem valuation represents the process of expressing a value for ecosystem goods or services (i.e. biodiversity, flood protection, recreational opportunity)” (Farber et al., 2002). As value is use-value, the valuation of an object is the act of giving a use-value to it, thus defining the object, the user, and the relation between both.

They try then to distinguish between intrinsic and instrumental value. Intrinsic value arises when someone wants to sustain or protect an object, just because it deserves to exist, i.e. "irrespective of human satisfaction" (Farber et al., 2002). If we believe that some ecosystem or species, for instance, deserve the right to exist, apart from any human consideration, then we can deduce from this assumption the value of all other objects: "the value of any action or object is measured by its contribution to maintaining the health and integrity of an ecosystem or species, per se, irrespective of human satisfaction" (Farber et al., 2002). These are intrinsic values, as the ones Costanza and Hannon tried to calculate in several papers (Costanza and Neill, 1984; Hannon, 1998). For each object, one could therefore attached a right to exist, and then define the intrinsic values of all object, by relating them to the goal: "we must preserve this object". One object can then have multiple intrinsic values. A problem arise thus when two object deserves the right to exist, but cannot exist at the same time. Intrinsic values in both cases will be contradictory: how to chose between intrinsic values then?[19,20]

On the other side there is what Farber, Costanza and Wilson call instrumental value: "instrumental values reflect the difference that something makes to satisfaction of human preferences. Instrumental values, such as economic values, are fundamentally anthropocentric in nature.". This is very close to the definition of "value" that they gave at the beginning: the only difference is that the user is now precisely defined as human.[21] According to them, one example of instrumental values is economic values; so the economic value of one object is for them its contribution to the user satisfaction. They do not therefore see any difference between exchange value (or economic value) and use-value, or more precisely they think that exchange value can be calculated just looking at the use-values.[22] They recognizes that "some needs may not be reducible to money or time", but they overall agree on the way neoclassical theory attributes economic values to all objects, i.e. that "the marginal utility of the goods ... can be used to explain their exchange value" and that "time or money can ... be used as a standard of measure of use value" (Farber et al., 2002). If there is no price on an object, a contingent valuation can be made by asking people

[19]These values are still given in relation to human choice (about what deserves the right to exist), so in a way I would still call it "use-value", even if the goal of this value is precisely to stop using or destroying the object. If no one believe that there is a right to exist for that object, then a set of intrinsic values disappears. And the problem of social choice (how to choose between different use-value?) appears again when some rights to exist are contradictory: how to choose between different rights to exist?

[20]In Costanza and Hannon (Costanza, 1980; Costanza and Neill, 1981; Hannon, 1998), the nature has a right to exist, but not individual ecosystems: they could be substituted, as, in these papers, the objective of nature is to maximize its net output, not to protect each ecosystem individually.

[21]Again in my opinion this is a definition of use-value.

[22]By overlooking this distinction, there is an implicit justification of the economic process of accumulation of exchange value. Economic growth is justified in the sense that, because it provides more exchange value, it provides more use-value. Capitalism is then justified, as a process that attributes exchange value to an object, and as a process that accumulates exchange-value.

what they would offer to protect the object (Willingness to Pay) or what the would receive to accept the destruction of the object (Willingness to Accept). And in order to go beyond personal utility, such contingent valuation could be made in a deliberative form between several people: this may help to construct a social value, and thus solve the social choice problem.

Finally they talk about another kind of value: ecological value. This value is different from use-value because "one cannot talk about 'value' as the degree to which an item contributes to achieving a goal in this context since there is no conscious goal being pursued" (Farber et al., 2002). Ecological value actually could refer to two different relations:[23]

1. Ecological value could mean "the degree to which an item contributes to an objective or condition in a system ... For example, one could talk about the value of particular tree species in controlling soil erosion in a high slope area" (Farber et al., 2002). An other definition can arise in the context of natural selection, when "one species is 'valuable' to the survival of another species. Extending this logic to the co-evolution of humans and other species, we can talk of the'value' of natural ecosystems and their components in terms of their contribution to human survival". Here we find again the definition of intrinsic value.

2. Ecological value could also mean energy-value (Costanza, 1980; Costanza and Neill, 1981; Costanza and Hannon, 1989). The goal of the energy theory of value is, for them, to "explain exchange values", i.e. monetary or economic values. They think that exchange values could be explain if it is possible to find the "'primary' input to the production process",[24] but "neither labor nor any other single commodity was really 'primary"'. Labor cannot therefore explain exchange values.[25] The energy theory

[23]The Hence distinction appears in Winkler (2006) between the "economic-ecological analogy" and the "energy theory of value".

[24]As regards this primary input, they are referring to the principles of the production-based theory developed by Samuelson (1966): for him, there is a possibility to calculate positive prices from a system of process exchanges if there is only one exogenous input (i.e. an input not produced by the system), if there is only single production and if there are constant returns to scale. The last point have been proved wrong by Sraffa. The first point is true, but it must be understood in a mathematical sense, not in the physical sense: if there is more than one primary input, the system will become indeterminate (an exogenous information must be added, for instance information about the distribution of the surplus).

[25]They also assert that the classical problem of Smith and Ricardo about finding the invariant measure of value can be reduced to the problem of finding the real primary input to the production process. They acknowledge that the classical problem was solved by Sraffa with his standard commodity of value, but they say that "the exchange values would not be independent of demand as Sraffa claimed" and that "Sraffa's [mathematical proof] did not constitute a price theory in the sense of establishing the process of price determination" (Farber et al., 2002). The first point is wrong, because Sraffa never claims that his prices where independent from demand, he says that its price are only dependent on the conditions of production and distribution (and of course conditions of production could change if there is a change of demand); and about the second point, it is true that Sraffa's theory helps to calculate the price of production but does not explains how people put prices in the corner shop. Nevertheless I do not see why this would be a reason to reject the first step (see also

> of value postulates "that, at least at the global scale, free or available energy from the sun (plus past solar energy stored as fossil fuels and residual heat from the earth's core) are the only 'primary' inputs to the system" (Farber et al., 2002). Hence energy is the primary input of the production system and it can explain exchange values: "it appears that the empirical link between available energy and economic value is rather strong" (Farber et al., 2002).

However, if the energy theory can explain exchange values, why can labor not do the same, as labor could be reduced to an average amount of energy? Furthermore is it possible that, at the same time, the marginal utility and the energy cost of production explain the exchange value of the same good, knowing that "Sraffa's model of reproduction prices – the basis of energy-value analysis in practice – is to demolish the neoclassical demand and supply approach to value based on marginal utilities and marginal products" (Burkett, 2006, p. 41)?[26]

5.1.7 Stahel

On this debate around value, Stahel (2005) goes on the opposite line of Farber et al. (2002). According to him use-value is the source of wealth, but is definitely different from exchange value: "increased (re)production of exchange-values does not necessarily mean an equal increase in human wealth (in many cases even the inverse correlation holds)" (Stahel, 2005). He agrees with the definition from Smith of use-value, i.e. "the utility of a particular object" (Smith, 1776, cited in Stahel, 2005)[27] and for him, exchange-value is defined as market-price.

The point of his contribution is twofold. First he wants to demonstrate that both use and exchange values express an "emergent, context dependent relational property". Concerning use-value, this is clear because:

Sinha, 2012). Anyhow, the energy theory of value does not solve those both points.

[26]Winkler (2006) actually tries to bring closer both approaches, but the result is yet another neoclassical model of production. In his model, the "world comprises a simple ecosystem, consisting of wilderness and bison and the interdependence between them. But in addition the model also incorporates a simple economy, where humankind can assign labor between" producing food through farming or hunting bisons. He assumes that society "agrees on a value system"; this system will attributes values to commodities "ex ante to guide further actions". It is clearly a system that allocates use-values, in a anthropogenic way (but not necessarily anthropocentric, because protecting nature could be one goal of the society). In effect, that means choosing an objective function for the society (e.g. maximizing well-being depending on consumption and the environment left) and linking it with environmental and ethical constraints. He then looks for sustainable paths for the economy and the environment. Thus he is actually dealing with a neoclassical model with inter-temporal allocation of initial stocks. Distribution depends on the productivity of the factors of production, and he can deduce shadow prices of the environment by determining the amount of well-being the environment can offer. He can also deduce the shadow prices of the constraints by looking at the "cost" of well-being the society is willing to sacrifice in order to respect the constraints (present and future costs, as this is an inter-temporal analysis). However, unfortunately this has nothing to do with a Sraffian analysis of exchange values and distribution.

[27]It is thus the same definition as Farber et al. (2002) use for "value".

> "use-value is realized only in the relational act of consumption, as a subset of all different potential utilities of a given good or service. This process is clearly context dependent: it will depend on the material (or informational) content of the particular commodity, but also on the environmental, socio-cultural and individual (subjective) context in which it is consumed" (Stahel, 2005).

Regarding exchange-value, this have been demonstrated by Sraffa:

> "different subsistence levels (seen as historically determined and thus varying over time according to the relative political force of the different classes) ... lead to different distributions of the product between wages, benefits and rent. These different levels thus lead to different relative exchange values of the commodities depending on the degree of labour-intensiveness of their production. In fact, this variability of the relative exchange-value of different commodities was the basis of Sraffa's still unanswered critique of the very notion of neoclassical capital" (Stahel, 2005).

The second point of his contribution is to call for an approach of the economy as a complex, ever-changing object of study, very much in the line with Spangenberg (2005):[28] "this non-linearity, scale and context dependency of any value is particularly true for what Funtowicz and Ravetz called emergent complex systems, which, as we saw, is the case of the human economic system"

[28]On the evaluation debate, Spangenberg (2005) defines three different positions:

1. Partisans of strong comparability and commensurability of all objects: they think that there exists "a common unit of measurement of the different consequences of an action based on an ordinal scale, like monetary value" (Spangenberg, 2005);
2. Partisans of strong comparability and weak commensurability: they think that there exists "a common measure based on an ordinal scale of measurement", i.e. that we can find "the existence of a single comparative term like 'utility' by which all different actions can be ranked" (Spangenberg, 2005).
3. Partisans of weak comparability: they acknowledge that sometimes no common measure can be found between objects but they believe that, in such situation, "irreducible value conflicts are unavoidable but compatible with rational choice, employing practical judgment" (Spangenberg, 2005).

According to Spangenberg weak comparability should be a basic concept for ecological economics, because "as far as we know there is no common factor, decisive for social cohesion, human satisfaction and the integrity of ecosystems" (Spangenberg, 2005). Thus ecological economics should stand against the neoclassical theory, which is based on the assumption that there are strong comparability and commensurability of all objects. Nevertheless, he thinks that this latter theory can give some insights about the sustainability of the economy through the capital stock approach, i.e. the calculation of total wealth indexes (for a criticism of such calculations, see Thiry and Roman, 2014).

He argues that the economic system is a complex one, as "the behaviour of individual actors cannot be aggregated into a macro figure either mechanically or statistically, and as the patterns of exchange between actors are variable and evolve as well". Thus prediction cannot be done, and in particularly there should be no assumption on long-term equilibrium. This point was, for Spangenberg, demonstrated by Sraffa: "regarding ... the development towards equilibrium, Sraffa could show nearly 80 years ago that the assumed decline of marginal cost and utility leading to equilibria is the exemption rather than the rule" (Spangenberg, 2005).

(Funtowicz and Ravetz, 1994b; Stahel, 2005). Hence there is no possibility of "perfect foresight and complete control" (see also O'Connor, 1994b on that point) and no possibility of finding sustainable prices within the free-market regulation process as "no single perspective from within a subsystem of fewer dimensions can fully encompass the reality of the whole system" (Funtowicz and Ravetz, 1994a).

Stahel then compares the economic process with the dissipative structures described by Prigogine (1972): for him social and ecological wealth creation, i.e. use-value creation, is similar to the creation of far from equilibrium negentropy into dissipative structures. This kind of structures creates order from chaos and, for Stahel:

> "as an extension of the process of cosmological and biological evolution, the driving force of any economic process (although not necessarily its outcome) is to generate ordered, low entropy structures such as houses, bread and computers ... If we take a long-term, cosmological perspective, ... the general evolution of our universe as a whole and of our biosphere in particular, seems to be characterized by an increasing complexity and diversity of life-forms" (Stahel, 2005).[29]

Finally Stahel draws a relation between this analogy and the post-normal value theory that he wants to develop, following Funtowicz and Ravetz (1994b). The post-normal theory of value helps to take decisions in front of complex problems (such as: is this project sustainable or not?); it starts from the recognition that "there are different competing and equally legitimate perspectives in each evaluation procedure" (Stahel, 2005) and that the (capitalist) economic one is just one of them. Then,

> "the role of expertise and traditional evaluation procedures ... is to provide not only quantitative, but qualitatively sensitive information input for decision making. At the same time, it has to recognize its own limitations: ... it cannot give us the whole picture. Moreover, these inputs will be considered within the communications and political framework [in a self conscious way]" (Stahel, 2005).

And in order to adopt rational decisions in situations including "risk, uncertainty and different legitimate perspectives", "the inclusion of the extended peer communities becomes a methodological as well as an ethical need" (Stahel, 2005).

[29]On that point I would be very prudent before asserting that evolution follows a path leading to continuously ever-increasing complexity (how much impressively complex species have disappeared? Are we that complex?). The same kind of "trend to complexity" can be found in the work of Passet (2010): again, I am very doubtful in front of such assertions.

5.1.8 Patterson

Patterson defines ecological prices as "the weighting factors inferred from models which describes energy and mass flows through ecological and economic systems" (Patterson, 2002). They represent also "ratios that measure the 'value' of an ecological commodity - e.g. solar energy per kilogram of apples" (Patterson, 2002). But what is "value"? Patterson talks about value "in terms of the biophysical inter-dependencies in the system" (Patterson, 2002). This is why the value measured by ecological prices is different from the value measured by the market, which is "based on consumer preferences and other factors that determine the exchange value in markets" (Patterson, 2002).

Ecological prices thus measure "*biophysical interdependencies* (or contributory values) implicit in the global ecological system and its economic subsystem" (Patterson, 2002). The goal is to highlights some processes or some resources which are important for the reproduction of the system, while there importance is not reckoned by usual price system. For instance,

> "it is unlikely that the value of protozoa in the ecosystem would be measured in a [Willingness-To-Pay] survey, whereas in ecological pricing, the value of protozoa in the ecosystem would be taken account of by the ... linkages they have with other components of the system" (Patterson, 2002).

Thus this approach is seen as "a complementary approach" to neoclassic valuation, and could be used "as a component of a multicriteria framework" (Patterson, 2002).

How does it works? Patterson writes down the equations representing exchanges between ecological and economic processes. In order to have prices which "make ecological sense" (Patterson, 2002), the processes must:

- obey to the First Law of Thermodynamics, i.e. mass and energy inputs must equal mass and energy outputs for all processes;
- refer to the Second law of Thermodynamics, i.e. "a degradation of the (thermodynamic) value of energy and materials" (Patterson, 2002) must appear;
- be open, because ecological and economic systems are open systems;
- have "multiple inputs and outputs (joint products)" (Patterson, 2002);
- be interdependent;[30]
- be part of a dynamic system, i.e. be subject to change in the course of time: "ecological system will most likely not be at equilibrium" and "economic systems at any point of time are most likely not to be at equilibrium" (Patterson, 2002).

[30]Patterson do not define interdependence in a mathematical way, and makes no observation about the difference between basic and non-basic goods or processes.

In order to calculate ecological prices, Patterson then develops the following model:

$$\mathbf{Ap} + \mathbf{e} = \mathbf{Bp} \tag{5.30}$$

With $\mathbf{A}$ and $\mathbf{B}$ the matrices of input and output coefficients, $\mathbf{p}$ the column vector of prices, and $\mathbf{e}$ the vector of "residuals". These residuals appear when there are two or more processes producing the same commodities, but with a different efficiency. A regression method is thus used to find the "average" process, such as constrained least square method. Recently he has developed "an Eigenvalue-Eigenvector" method to find these average prices (Patterson, 2002; Patterson et al., 2006). The goal is to find the minimum eigenvalue λ_{min} that satisfy the price equation:

$$[\mathbf{B} - \mathbf{A}]^t [\mathbf{B} - \mathbf{A}] \mathbf{p} = \lambda_{min}\mathbf{p} \tag{5.31}$$

Patterson relates his approach of ecological prices with:

- the method developed by Odum (1996) to calculate transformities: "the only difference is that transformities only focus on energy transformation, whereas ecological pricing focuses on both energy and mass transformation" (Patterson et al., 2006). Patterson rejects the view that ecological prices should be expressed in energy equivalent, because solar energy is not not the only input to the system (geothermal, uranium and fossil energy can also be listed) and because he is dubious about the "maximum power principle" (Odum, 1996) which stands that ecological systems tends to favour more energy efficient processes: "it is doubtful whether an ecological-economic system does (or for that matter should) operate according to just one objective function" (Patterson, 2002). According to him whatever numeraire can makes the point, as relative prices will not change: "indeed, the Economic Output quantity ($ value added) can be used as the numeraire if so desired - this may be imperative in terms of 'communicating' the result of any ecological pricing exercise" (Patterson, 2002).
- the method developed by Sraffa (1960). However, for him, Sraffa's model is "an equilibrium model generating equilibrium prices, as the equation structures only permits equal 'interest' rates (efficiencies) for each process" (Patterson et al., 2006) and Sraffa's method is violating thermodynamics laws, because all exchanges are not taken into account (waste and natural extractions are ignored) and because there is no assumption on energy and mass balance (the surplus is created out of air) (Patterson, 1998). Nevertheless, Patterson thinks that Sraffa's approach can become "the basis for objectively measuring the contributory value of species, in

> terms of how one species contributes to the value (livelihood) of other species" (Patterson et al., 2006)[31].

Patterson finds that "the ecological prices (with the exception of fossil fuels) show a good correspondence with actual market prices ... [except for] the ecological price [of fossil fuels, which] is about seven times the market price" (Patterson, 2002), thus in agreement with other studies showing that fossil fuels prices are forced to remain low because of political decisions and that the elasticity of the GDP with fossil fuel is underestimated (Giraud, 2014). An other founding is that, in an attempt to compare Costanza's famous study on the value of nature (Costanza et al., 1997) with his method, "the value of primary ecological inputs is $24.73 trillion, compared with $25.79 trillion for global GDP, giving a ration of 0.98" (Patterson, 2002), while Costanza et al. (1997) found a ratio of 1.32.

On this last attempt, my point of view is that he confuses the signification of value and distribution in Sraffa's system. Value for Sraffa depends on the exchanges that will have to occur in order to reproduce the process and on the distribution of the surplus (in the case of non-basic goods, their prices only depend on the latter). Sraffa's equations of production can be written in this way:

$$(1+\pi)\,\mathbf{Ap} + w\mathbf{l} = \mathbf{Bp} \tag{5.32}$$

With $\mathbf{A}$ and $\mathbf{B}$ the matrices of input and output coefficients, $\mathbf{p}$ the column vector of prices, $\mathbf{l}$ the column vector of labor coefficients, π the uniform rate of profit and w the uniform wage.

If there is no surplus, prices express the exchanges in the market that must happened to allow the identical reproduction of the system. Hence, in Sraffa, the profit rate and the wage are equal to zero, and in ecological pricing, either the value of the non-produced input is equal to zero, or it is not possible to solve the system. Thus the energy-value theory collapses, as it states that the value of all commodities can be deduced from its embodied quantity of energy: if energy has no value, all commodities should have no value.

If there is a surplus, in Sraffa's analysis, it is also sold in the market. As the companies does not need this surplus, it is given - or distributed - to the agents of production (capitalists or workers). But in ecological pricing models, there are no agents. Thus, if there is a surplus (as for instance in Costanza and Neill, 1981; Patterson, 2002), the surplus is "distributed" to the non-produced input: this is actually justified by ecological pricing authors on the footing

[31] I think Patterson is wrong when he considers Sraffa's theory: it is a non-equilibrium theory. The fact that there is an equal "efficiency" for all processes is because Sraffa introduces differential rent as the way to compensate for inequalities in the productivity of one factor of production. And the fact that Sraffa is not dealing with natural resources and waste is not because he thinks that value can be created with air, but that his only concerned is about exchange of marketed goods and services within interdependent systems of production. Natural resources and wastes are thus considered as non-relevant for his system of production, because they are not priced: there is no economic exchange with nature (to rephrase Perrings, 1987, there are only "exactions" and "insertions").

that the real value added comes from the sun, or from other primary inputs. Hence prices reflect the amount of energy, or primary inputs, that are needed to produce any commodity. However, what Patterson do not acknowledge is that this "distribution" forces the total value of non-produced inputs to become equal to the value of the surplus (it is equivalent to say that the "owners" of the non-produced input receive the whole surplus). When Patterson therefore finds that the net inputs (solar and geothermal energy, fossil fuels, uranium) have a total value of 0.98 times the value of the net output (global GDP), this is actually an imposed result of its invisible convention about the distribution of the surplus.

5.1.9 Sciubba: extended energy accounting

Linking the field of ecological economics with the field of industrial ecology (Frosch and Gallopoulos, 1989; Ayres, 1989; Erkman, 1998), Sciubba (2005) wants to revive the energy theory of value. But as "all applications show that introducing second law considerations in the analysis leads to results that provide more precise and useful information for the design engineer, as well as for the energy planner" (Sciubba, 2005), he chooses exergy rather than energy for his analysis.

Exergy can be defined as the embodied energy of a unit of matter (or energy) which is available to perform a physical work. In the definition used by Sciubba, the exergy of a unit of mass (or energy) at state 1, by comparison with a reference state 0, is the following:

$$e_1 = h_1 - h_0 - T_0\left(s_1 - s_0\right) + \sum_i \left(\mu_i c_i - \mu_0 c_0\right)[kJ/kg] \tag{5.33}$$

With h_i the specific total enthalpy, T_0 the temperature of the reference state, s_i the specific entropy, μ_i the chemical potential and c_i the relative concentration. This definition favors an engineering point of view, as Sciubba chooses to "neglect other lesser contributions (molecular vibrations, nuclear, magnetic, etc.)" (Sciubba, 2005). The chosen reference state is the environment defined as "the portion of the universe that is outside of the boundaries of the modeled system" (Sciubba, 2005). As the quality of energy decreases after each round of production, the exergy of the outputs of an industrial process is always lesser than the exergy of its inputs.

The exergetic cost of a product is the sum of all exergetic inputs required directly and indirectly to produce it, divided by the product exergy (and the conversion efficiency of a product is the inverse of its exergetic cost):

$$c_i = \frac{\sum \mathbf{E}_{input}}{\mathbf{E}_{product}} \tag{5.34}$$

Sciubba's goal is "the development of a formally complete costing theory based on exergy metrics", because "exergy destruction ... represents the driving force of all life forms" (Sciubba, 2005).[32] He performs the reduction of flows of matter and energy used in production into exergy values:

> "A material stream is assigned a total (or cumulative) exergetic content defined as the sum of its raw state exergy and of all the net exergetic inputs received, directly or indirectly, in the extraction, preparation, transportation, pretreatment, and manufacturing processes" (Sciubba, 2005).

The problem of this reduction is that matter quality is not taken into account anymore: usually people do not choose a material over an other material just by looking at their relative exergies. Thus Sciubba defends himself by arguing that:

> "extended exergy does not define a scale of practical or virtual preferences: it enables, though, a process engineer or an energy planner to exactly compute the resource-equivalent consumption embodied in the unit mass of two different artifacts ... Extended exergy is an indicator of resource consumption, not of individual or social preference" (Sciubba, 2005).

However, for him economic value is nonetheless related with exergy: "it clearly appears that exergetic content, and not capital, is the correct measure for the worth of a commodity or a service, and that the monetary price ought to reflect this new measure of resource consumption". Just looking at their relative exergies, one can therefore know which material is more valuable, in an economic sense. But is the economic value not expressing individual or social choice? Sciubba's answer is that "when making a choice in an economic sense, one is confronted with three different quantities: monetary value, use value (economic value to the purchaser), and intrinsic (resource-based) value" (Sciubba, 2005). Thus for him exergy can be used to reflect the intrinsic (exergy-based) value of a product, which should not be confounded with exchange value, the latter being synonym of use value and being usually measured with money: "anything can be money, from stones and metals to paper, and that what makes these things money is not what they are, but what they are used for. Furthermore, their value as money is separate from their intrinsic value" (Sciubba, 2005, he follows an argument developed by Friedman, 1992).[33]

[32] Here there is a confusion about the mandatory conditions for production and the source of exchange value, as Sciubba states that there exists an "intrinsic and direct correlation between exergy and economic value". Economic or exchanged value, expressed by money prices, is a result of a capitalist way of producing commodities, not the expression of an intrinsic value correlated with exergy.

[33] I think Sciubba is wrong on two points: first an intrinsic value for a commodity does not exist, value is always relative to a system of production and consumption. Second use value is not reflected by exchange or monetary value. Exergy is not correlated with use value, but can be correlated with exchange value, as the environment and more specifically the use of energy is a condition for the production of commodities. Exergy is an "indicator of resource consumption", but not more than that.

The originality of Sciubba's proposal lies in the reduction of capital, labor and environmental remediation expenditures into exergy flows. To know the extended exergy content of capital (ee_{cap}, equivalent for him to the extended exergy content of money), Sciubba multiplies the monetary cost of the capital with the extended exergy coefficient of capital (K_{cap}). This latter coefficient is given by the global exergy input ($\sum \mathbf{E}_{input}$) divided by the amount of global monetary circulation ($M2$):

$$ee_{cap} = c_{\$} K_{cap} = c_{\$} \frac{\sum \mathbf{E}_{input}}{M2} \tag{5.35}$$

If there is a creation of money while the input of exergy inside the economy remains constant, the extended exergy content of capital will therefore go down. According to Sciubba the choice of $M2$ is "arbitrary": we come back here to the question of building a bridge between two value systems. Two problems arise then: on one hand, money can be used to evaluate environmental services, and on the other hand exergy content can be different depending on the country we are looking at (thus it is not an intrinsic value anymore, it depends on social choice).

The reduction of labor into exergy is done by dividing the exergy input of one sector by the number of working hours in that sector:

$$ee_{lab} = n_{hours} K_{lab} = n_{hours} \frac{\sum \mathbf{E}_{input,Sector}}{n_{hours,Sector,}} \tag{5.36}$$

This reduction is essential for Sciubba as "the attribution of a purely monetary value to labor is unsatisfactory because it assigns a higher weight to market conditions and financial considerations than to social, technical, and environmental issues" (Sciubba, 2005). Hence this reduction tries to mitigate this, in a politically neutral way, as "EEA is not a social or political theory" (Sciubba, 2005).

A little exercise may help to understand the theory of value of Sciubba: let us look at one country, producing only one commodity, by the help of energy, money and capital.

$$\begin{array}{ccccc} Exergy_{input} & labor & capital & & Exergy_{output} \\ \mathbf{E}_{input} & n_{hours} & M2 & \rightarrow & 1 \end{array} \tag{5.37}$$

We can calculate the exergy extended content of capital and labor flows:

$$ee_{cap} = M2.K_{cap} = M2 \frac{\mathbf{E}_{input}}{M2} = \mathbf{E}_{input} \tag{5.38}$$

$$ee_{lab} = n_{hours} K_{lab} = n_{hours} \frac{\mathbf{E}_{input}}{n_{hours}} = \mathbf{E}_{input} \tag{5.39}$$

The exergy cost of the commodity then equals to:

$$\frac{\mathbf{E}_{input} + ee_{lab} + ee_{cap}}{1} = \frac{\mathbf{E}_{input} + \mathbf{E}_{input} + \mathbf{E}_{input}}{1} = 3\mathbf{E}_{input} \tag{5.40}$$

We can therefore see that the theory of value of Sciubba is constructed in order to give an equal weight in the production of value to capital, labor, and energy. More precisely the value coming from the stream of capital equals the value coming from the stream of labor, and this value is equal to the value of the exergy input of the system (whereas in Costanza, 1980; Costanza and Neill, 1981 and Hannon, 1998 for instance, the value of the energy input is the sole stream of value coming from outside the system, labor and money capital are not accounted). Even if Sciubba claims that EEA is not a political theory, his theory of value is based on an implicit political decision about the distribution of the surplus: a theory of distribution where surplus is divided into three equal parts, which remunerate energy, labor and capital, can be deduced from his theory.

Finally Sciubba adds to that the cost of environmental remediation: he is against the reduction of this cost into money through Willingness To Pay studies because:

> "willingness to pay and the attitude toward a sustainable resource exploitation are different in different countries, and may well vary in time: therefore ... the method actually promotes an *unfair transfer, not only of the pollution, but also of the associated health risks from one region to another*" (Sciubba, 2005).

Indeed, "the poor sell cheap" principle (described byMartinez-Alier, 1995) tells us that the pollution cost of remediation may be lower in poor countries: thus these kind of studies will promote a displacement of polluting industries in such regions. Hence Sciubba defines "the environmental pollution avoidance cost, calculated as the additional extended exergy expenditure that is required for bringing all environmental discharges down to a zero physical exergy level" (Sciubba, 2005). Sciubba's goal, by doing this reduction, is to provide "a consistent basis for the calculation of the environmental externality" (Sciubba, 2005). This cost is to be added to the exergy inputs of the product in order to know his real cost. If we take again the previous example, the exergy cost of the commodity becomes:

$$\begin{aligned} &\frac{\mathbf{E}_{input}+ee_{lab}+ee_{cap}+\mathbf{E}_{rem}+ee_{lab,rem}+ee_{cap,rem}}{1} = \\ &\frac{\mathbf{E}_{input+rem}+\mathbf{E}_{input+rem}+\mathbf{E}_{input+rem}}{1} = 3\mathbf{E}_{input+rem} \end{aligned} \tag{5.41}$$

5.1.10 Conclusion on the debate around the theory of value

Sraffa's theory is an exchange value theory: the goal of the theory is to understand how these values are related with the result of the distribution of the surplus. The exchange value of a commodity depends on the conditions of production and distribution of the surplus: Stahel (2005) agrees with this, as opposed to Farber et al. (2002), who relate the exchange value to consumer's preferences.

Georgescu-Roegen (1979)shows that an energy theory of value is reductive, because "matter matters too" for the process of production. Furthermore he shows that distribution of the surplus can influence the price of commodities, which is not the case in the energy theory of value models: the value of the surplus, in these models, is simply the value of the net inputs, which is equivalent to say that the surplus is entirely given to the owners of such net inputs.

But still, Costanza ((1980; 1981; 1984)) and Hannon (1998) want to calculate the value of the environment by including environmental processes into Sraffa's system, and by replacing labor net input by solar energy net inputs. The energy needed to produce the economic production is then known, and we can compare this amount with the energy needed by the environment. Patterson (2002; 2006) does the same calculation, but with several environmental net inputs. Sciubba (2005) finally also reduces the value of commodities into their exergetic contents: his goal is not to find the value of the environment, but the "true" value of the commodities.

The problem with these attempts to calculate the value of the environment from a Sraffian framework is twofold. First the influence of the distribution upon values is not taken into account, distribution is fixed (same weight between energy, capital and labor for Sciubba, surplus distributed to the net inputs in Costanza, Hannon and Patterson). In the case of the energy theory of value, if the distribution were different, we could not talk about a pure energy theory of value anymore, because prices would not reflect the consumption of energy anymore.

Second, adding natural processes which do not need any labor to be processed means that the classical labor theory of value must be abandoned. Even if all surplus goes to labor, prices will not reflect the labor embodied into the commodities: natural resources will still have a price (because they are produced) and thus labor would not be the sole producer of exchange value anymore. My point of view is that this goes directly against the political economy of Sraffa. Furthermore, this leads to the position that exchange value is related to the possession of a commodity, and then for instance royalties for the use of natural resources are justified. This is why I would prefer to keep the natural resources out of the scope of priced commodities (see also subsection 6.2.2.2).

This does not mean that the economic world is independent from the natural one. Exchange value cannot be created without the use of natural resources and services. We still need a biophysical theory of production to explain the limits to economic activity that are imposed by the environment, as wanted by Christensen (1987; 1989). However, my point of view is that this biophysical theory is separated from the economic theory of exchange value. The energy theory of value is not interesting if we want to value the environment (as the value of the environment is infinite) but it is interesting to know what is the energy needed to produce a given amount of commodities. This accounting (which can be extended to all sort of natural resources) would help policymakers to know which technology is the most energy efficient. This is the goal of the analysis of Judson (1989), for instance. Hence the environment could be better protected, if the energy efficiency (and all natural resources efficiency) were to be criteria for optimisation.

5.2 The second direction: ecological conflicts and Classical economics

5.2.1 England

England (1986) has been one of the first to specifically talk about the ecologization of Sraffa, and the link that could be drawn between Sraffa and ecological economics in order to compete against the neoclassical theory.

He first describes how is depicted production in the neoclassical theory: first there is a distinction between inputs and factors of production,[34] then inputs are transformed into commodities. Thus there is no importance "attached to the historical processes whereby 'factors of production' have come into being" (England, 1986). He then describes the neo-Ricardian theory: natural resources are said to be non produced and in short supply (so they can receive a rent), quantities of inputs (not different from factors of production) "can vary historically". Production is divided between inputs for an other cycle of production and surplus, and then surplus is distributed among the population. In order to define the surplus, one must look at the physical requirements for the system of production to carry on. He touches upon the problem of the definition of labor in this theory: is it a produced input, or non-produced input? I.e. is consumption a process included in the economy or not? England connect this point with the dichotomy between objective and subjective needs (see also Martins, 2013 and subsection 5.2.8 on this point). According to him, if labor is seen as an input, then part of the consumption becomes a requirement for the system, and then becomes an objective need. However, the consumption process "is not governed by profit criteria" (England, 1986), and this may explain why Sraffa chose to represent labor as a non-produced input.[35]

[34] An input receives a price, a factor of production receives a revenue: distribution of revenue is determined after the price assessment, the latter occurring through the mechanism of offer and demand. The distribution of revenue does not impact the value of the surplus which is distributed. If there is a change in distribution, for instance through taxation, the demand will change and thus prices will change. In the Sraffian theory, distribution influences prices, and prices and revenues are simultaneously determined.

[35] In his article "Market and non-market determinants of private consumption", Cogoy (1995) asks what would be the impact of including the "consumption process" inside the market. As the output of this consumption process is enjoyment and not labor force, Cogoy does not directly answer the question of England about the integration of consumption into Sraffa's system. Nevertheless his approach is interesting. Consumption is here "viewed as a process having enjoyment targets as outputs and requiring market and non-market inputs" (Cogoy, 1995): it represents the time spent in supermarkets, repairing the house to have a comfortable dwelling, waiting at the gas station, etc. .

Considering this "process", he then looks what are the changes if a company decides to sell the "consumption" service:

- on the economic side, will there be more or less profits? Using Sraffa, he shows that the rate of profit would not change (as the service "consumption" is a non-basic good) but that the volume of profit would increase.
- On the efficiency side, he wonders if it will be less time-consuming, thus if it will increase the leisure time for the workers (the time spent in the consuming process would be available for leisure, but in order to buy the "consumption" service, workers

England then talks about the new (at that time) field of environmental economics, through two of its major contributions to economic science: the importance of wastes (because they harm the environment, and thus harm both life quality and natural resource production) and the definition of natural services (or ecosystem services). According to him environment and society should be seen as a whole, and not as two separate blocks.[36] He thinks that solution to environmental problems can be found by changing "the social organization of production" and not just through market regulations. This is the reason why he thinks that both environmental and neo-Ricardian schools should work together.

In order to initiate the movement, he develops a dynamic neo-Ricardian model, with one produced commodity, corn, and one jointly produced waste, emission. To produce one unit of corn and e units of emissions, there is a need for a units of corn, a quantity h of human labor, n_1 units of land, n_2 units of sunlight, n_3 units of precipitation and n_4 units of CO_2, with land, sunlight, precipitation and CO_2 natural resources with no price and no rent. There are several technologies to produce corn, depending on coefficients e, a, h, and n_i. Technologies with lower e (production of emission) have higher a and h coefficients (inputs of corn and labor). Furthermore, $\lim_{e\to 0} a(e) = \infty$ and $\lim_{e\to 0} h(e) = \infty$.

If there is no emission regulation, the chosen technology is written (e_0, a_0, h_0). If there is a regulation, the lowest level of emission possible is attained

would have to do more work).

- On the environmental side, he asks the question whether there will be an increasing awareness of environmental concern.

On all that points, there are no definite answers: it could be interesting to have a private sector for consumption, but it will not be interesting if the institutional and cultural contexts are not well taken into account. Depending on them, it could even be more interesting to go backward and to remove from the market some services.

This analysis is done along three different aspects (economy, efficiency and environment): there is no attempt to connect these aspects into a more global system. Sraffa is just used to illustrate the case; there is also no real attempt to integrate Sraffa into the ecological economics framework. And there are some misunderstandings of Sraffa, e.g. where Cogoy states that "the [Sraffa] methodology ... would have to be modified if more complex features of the economy, such as joint production, increasing return to scale, wage differentials, non-competitive markets, etc. were considered". I claim that this is wrong, and that the Sraffa system can cope with all this point without being changed.

But anyway the question of whether we need to integrate the consumption process (and why not even the "leisure" process) into the analysis is a good question: this is related to the question of the definition of the surplus of the economy. Should we take into account in the definition of surplus everything which is not consumed by an industry, or should we deduce from that what is necessary to live (the means of subsistence)? The second option was chosen by Smith and Ricardo but the first one is more easy, maybe less arbitrary and was chosen by Sraffa. On that point, Richard Arena, during meeting in October 2014 in Nanterres University, Economix, underlined that it is not that easy to separate what is needed by the industry from what is superfluous. For instance, is the coffee break part of what is necessary in order to perform the process of production? Or is the coffee a part of the surplus consumed by the worker?

[36] This is why he is considered as one of the fathers of ecological economics.

when the corn input is equal to the corn output: this technology is written (e_1, $a_1 = 1$, h_1). England then writes down the price system, with wage paid in advance for the process of production:

$$p = p(1+r)[a(e) + wh(e)] \tag{5.42}$$

If the price of corn is the numeraire, the price system becomes:

$$1 = (1+r)[a(e) + wh(e)] \tag{5.43}$$

And we can find the relation between the wage and the rate of profit:

$$r = \frac{1}{a(e) + wh(e)} - 1 \tag{5.44}$$

Hence "the highest possible profit rate ... is realized when the real wage rate is zero and there is no environmental protection" (England, 1986). If the lowest emission is chosen, then the rate of profit and the wage becomes equal to zero, as production ceases. Between these two points, for each emission level, the surplus decreases and can be appropriated by wage earners or capitalists. According to England,

> "these results suggest that there is no single 'socially optimal' level of pollution.[37] Rather, various social classes stand to gain the most from different and conflicting levels of environmental quality. The particular level of environmental quality actually enforced by the state will presumably reflect the relative political power of those various social classes and hence their respective capacities to influence government decisions on environmental protection" (England, 1986).

From that analysis, England thinks that the notion of class struggle must be enlarged to take into account environmental problems:

> "In an earlier era of capitalist development, class conflict between workers and capitalists centered on such issues as the length of the working-day and the size of the bundle of wage goods customarily consumed by working-class households. Now, however, there are attempts by workers not only to escape from physically and mentally debilitating work environments through a shortening of the working-day but also to impose techniques of production on capitalists which improve environmental quality in the workplace and in working-class communities. Those proletarian efforts need to be recognized and incorporated within modern political economy" (England, 1986).

[37] Environmental economics asserts that a "socially optimal" level of pollution can be calculated (Coase, 1960), with the assumption that the agents are individuals that do not attempt to assemble in order to influence market prices.

This class struggle can then be seen as a fight between capitalists who want higher profits, workers who want higher wages and environmentalists who want environmental protections. The question is then: who are these environmentalists? Are they workers or capitalists? Or neither of two options, living in non-capitalist society? Or maybe there is no need to define a class defending the environment, as the protection of the environment will emerge as a social need, i.e. as a concern shared by everybody? Actually what we see is that, even if in certain countries it effectively emerges as a political consensus that the environment should be protected, the tension between this protection and the desire for higher profits and higher wages remain high and visible, and the protection of the environment needs the action of activists to survive as a political choice.

5.2.2 Perrings: rents and externalities

5.2.2.1 The physical system

Perrings tries to consider the impact of externalities generated by the economy on the environment, through a joint production model. Externalities are first defined in this way: "the basis of external effects is the non-independence of the preference and production functions of economic agents who operate within a common environment, but who do not meet in the marketplace" (Perrings, 1987, p. 1).

In order to take into account externalities, he wants to avoid the market solution prevailing in environmental economics, i.e. the introduction of taxes and subsidies or the definition of prices through subjective valuation. According to him this kind of solutions leads to the attribution of rights - to pollute or to extract - on resources previously considered as common goods, and furthermore does not revolutionize the way we look at the economic system.

Indeed, two strong hypotheses are always assumed in the neoclassical theory: environmental goods have no price - "free gifts" - and wastes can be emitted in the environment without cost - "free disposal". In ecological economics, for Perrings, both hypotheses should be rejected. In order to prove that, he constructs a world model, based on five hypotheses (Perrings, 1987, p. 18-21):

1. The system is thermodynamically closed (but not isolated), thus there are energy exchanges with the outside of the system (i.e. space) but no material exchange;

2. The system is not decomposable, i.e. economic and environmental processes are interdependent;

3. It is possible to represent the system through joint production processes, with a number of processes equal to the number of resources, each process using at least one input, each resource being produced by at least one process. These resources include for Perrings goods produced by the economy ("commodities") but also labor and natural resources: "what is

unusual is the inclusion in the model of environmental resources: those that do not have the status of commodities. Such resources are not valorized - they lie outside the the price system of the economy" (Perrings, 1987, p. 11);

4. Processes produce new resources, degraded means of production (equivalent to older fixed capital in Sraffa) and wastes (defined as the difference between the inputs and the two first kinds of outputs);

5. All technical coefficients are fixed, meaning that constant return is assumed, but technological changes are possible.

Perrings chooses to only consider material exchanges (Perrings, 1987, p. 19). A technology is defined in this way:

> "technology means the pool of knowledge that bounds all material transformations of the global system. It thus represents the sum of all the historically acquired chemical, genetic, intuitive, or recorded knowledge of material transformations" (Perrings, 1987, p. 21).

Technology is represented by two matrices $\mathbf{A}$ and $\mathbf{B}$ with, respectively, inputs and outputs coefficients:

$$\begin{aligned}\mathbf{A}(t) &= \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \\ \mathbf{B}(t) &= \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nn} \end{bmatrix}\end{aligned} \tag{5.45}$$

Both matrices are non-negative, and $\mathbf{A}(t)$ is non-decomposable. The n rows represent the n processes, and the n columns, the n resources.

Let $\mathbf{q}(t)$ be the line vector describing available mass in the beginning of each period of production. If the hypothesis about mass conservation (hypothesis 1) is retained, we can represent the constraint on the system in the following way, with $\mathbf{e}$ the column vector unity and $\mathbf{q}^t$ the transpose of vector $\mathbf{q}$:

$$\mathbf{q}(t)\,\mathbf{e} = \mathbf{q}(t+1)\,\mathbf{e} \tag{5.46}$$

$$\mathbf{A}(t)\,\mathbf{q}^t(t) = \mathbf{B}(t)\,\mathbf{q}^t(t) \tag{5.47}$$

We can define the rate of material growth of the system in this way:

$$g = \frac{\mathbf{q}(t+1)\,\mathbf{e}}{\mathbf{q}(t)\,\mathbf{e}} - 1 \tag{5.48}$$

The upholding of hypothesis 1 then leads to a rate of growth equal to zero. Hence, if hypothesis 2 is confirmed in reality, each time a model assumes a rate of growth superior to zero, there is an implicit assumption of free gift from nature.

Perrings then deals with the assumption of "free disposal" (Perrings, 1987, p. 28-29). This hypothesis implies the following relationship:

$$\mathbf{q}^t(t) > \mathbf{A}(t)\,\mathbf{q}^t(t) \tag{5.49}$$

Thus some resources are not used as inputs by the system and disappears. If hypothesis 1 holds, this can only be true for a subsystem inside the global system. At the global system level, we can only have:

$$\mathbf{q}^t(t) = \mathbf{A}(t)\,\mathbf{q}^t(t) \tag{5.50}$$

This latter equation means that if there is a technological change in one process, an other technological change in one or several other processes is implied, in order to keep true the mass balance principle. This also implies that within system with a stable technology, all wastes are inputs for other processes.

Perrings then looks at some possibilities in order to relax hypothesis 2 (Perrings, 1987, p. 31-33). System 5.45 would be partially decomposable into two subsystems if we could write it, through rows and columns permutation, as:

$$\mathbf{A}(t) = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} \\ 0 & \mathbf{A}_{22} \end{bmatrix} \quad \mathbf{B}(t) = \begin{bmatrix} \mathbf{B}_{11} & 0 \\ 0 & \mathbf{B}_{22} \end{bmatrix} \tag{5.51}$$

The first subsystem (on the first rows) is then input dependent on the second subsystem, whereas the second is not dependent on the first one. Perrings (1987, p. 33) then explains that the system may be considered decomposable if processes are distant in time. A technological change in one process will little by little affect all processes if the system is non decomposable, but some processes will wait several periods before being affected. We can then consider the system as decomposable during a short period of time: during this period, hypothesis 2 can be relaxed.

Perrings then introduces the assumption that each process is owned by a specific class of agents. If two processes are interdependent, it means that they both need at least one output from the other process to operate. An exchange is needed and Perrings defines it as a transaction: "A transaction implies the real exchange of the outputs of distinct processes to mutual advantage and by the agreement of the agent involved" (Perrings, 1987, p. 34).

However, is there always mutual agreement? Let the system 5.45 be composed of only two process with the following technology:

$$\mathbf{A}(t) = \begin{bmatrix} a_{11} & a_{12} \\ 0 & a_{22} \end{bmatrix} \quad \mathbf{B}(t) = \begin{bmatrix} b_{11} & 0 \\ 0 & b_{22} \end{bmatrix} \tag{5.52}$$

In this kind of system, owners of process 1 do not produce anything that can be used in process 2. There is no need for owners of process 2 to give a part of their output to process 1: there is no mandatory transaction. Perrings then introduces the terms "exaction" and "insertion" to describe the possible outcomes of such situation:

> "an exaction implies the forcible uncompensated acquisition of the outputs of one process by the agent(s) operating another process. An insertion implies the forcible uncompensated imposition of the output of one process, by the agent(s) operating that process, on another process" (Perrings, 1987, p. 35).

In system 5.52, there may be an exaction of resource 2 by the owners of process 1, or an insertion of resource 2 by the owners of process 1. This depends on power relationships between agents. An exaction can occur for instance when a process extracts a non renewable resource and an insertion when there is waste disposal in the environment, without, in each situation, an agreement with the "owners of the environment".[38]

Insertions and exactions are not fair, but they can be sustainable: for instance if the growth rate of process 2 is higher than the growth rate of process 1, the exaction is sustainable. If it is not the case, resource 2 starts being depleted.

As regards technological stability, Perrings (1987, p. 43) then inquires if a subsystem can at the same time conserve a stable technology while freely disposing waste in the environment. If hypothesis 2 is retained, then this can only be the case in a limited period of time, because all processes are connected. Perrings highlights here the difficulty of knowing both the distance between two processes (the time frame before one process is impacted by the change in an other process) and the technical relationship that exists between two processes. The global system cannot be controlled, and even not observed (i.e. we cannot understand all relationships that exist in the real world).

This allows Perrings to criticize the neoclassical approach about environmental problems: this approach assumes that when a resource becomes *relatively* scarce, its *relative* price will increase and new techniques of extraction and recycling will emerge. It assumes as well that it is possible to evaluate the *relative* cost of a pollution - which increases only if the pollution *relatively* increases - and then to develop control policies allowing to obtain the socially optimal level of pollution. There is no account of the absolute scarcity of some resources - because neoclassical economists assume that prices will force substitution - and the possibility of non-control of environmental conditions - because they say that it is just a matter of an efficient allocation of resources. Thus for the neoclassical economy there is no absolute limit of the economic subsystem, even if all economists agree that the Earth is not infinite.

The only possibility for the system to keep growing, is to continuously find new resources to deplete, i.e. to continuously change the existing technology: the magic key is to keep introducing new resources into the economic subsystem. And then maybe the global system will become controllable, but when

[38]This leads of course to the question: who are those owners?

this goal will be achieve, growth will end. Because there are some absolutely scarce resources, and because energy and matters are continuously degraded, so recycling cannot be complete.

5.2.2.2 The value system

Perrings investigates how the relationship between the economy and the environment affects the creation of exchange values. He starts with the definition of exchange value: "the value of a resource is defined to be a corresponding transaction weight fixed by the conditions of production, distribution, and exchange" (Perrings, 1987, p. 65). He is not considering use-value, but he points out that a resource will have a positive price only if it generates a positive marginal utility (Perrings, 1987, p. 65).[39]

But if this latter condition is necessary to have a positive price, it is not sufficient, as it also depends on ownership: only owned commodities can have a price, and commodities are defined in this way:

> "commodities in such a system imply resources that have value in exchange and are subject to well-defined rights of property. They include not only products in the usual sense of the word, but also labor and any valorized resource extracted from the environment" (Perrings, 1987, p. 11).

Labor is thus a commodity, but natural resources are not: they have no price because they are not subject to rights of property - "they lie outside the the price system of the economy" (Perrings, 1987, p. 11).

He then sets up the definition of a value system inside an economy:

> "the value system is defined to be the set of transaction weights governing the exchange of resources between the agents controlling the mutually dependent processes of a human economy. The value system is thus coextensive with the market" (Perrings, 1987, p. 65).

Interdependence between economic processes ensures that the input matrix is non-decomposable, and thus that there is one unique solution for each price. He adds then: "The value system is any system of weights establishing the ratio in which resources, defined in terms of property rights, are exchanged one for another" (Perrings, 1987, p. 66). Thus again ownership rights on resources are the way to know if there will be a price on a specific resource.

In order to define his price system, Perrings adds two hypotheses:

1. Prices depends on conditions of production and of distribution. The first means the technology used by the system, the latter the conditions governing the sharing of the surplus. In Perrings terms, conditions of distribution include "the extra-economic - cultural, legal, ideological, and

[39] This is rather strange: why at the margin? It seems sufficient to say that a good should generate utility if one wants to sold it with a positive price.

political - conditions affecting the distribution of income between the proprietors of distinct factors of production" (Perrings, 1987, p. 67).

2. There is a high degree of complementarity between resources.

This latter hypothesis explains why conflicts about the distribution of the surplus can occur. By assuming that there is competition between the different owners of the means of production, Perrings comes close to Marx: the only possibility for owners of the same mean of production to increase their share of the net surplus is to join forces against the owners of the other means of production (because competition ensures that they will get the same rate of profit on their shared resource, Perrings, 1987, p. 67-68). They will act like a *class*, in a Marxist sense: "the economic actors of interest are not individuals per se, but the group of proprietors of each set of perfectly substitutable resources advanced in production" (Perrings, 1987, p. 68). However, the fact that he connects the origin of the struggle in the limited supply of resources tells us that the capitalist system of production (and distribution) is not actually contested (see Burkett, 2006, section 5.2.6).

His price system with joint production can be written like this (Perrings, 1987, p. 71), without environmental resources (which bear no price) and environmental processes (which are not owned):

$$\mathbf{B}(t)\mathbf{p}\left(t+1\right) = \mathbf{A}(t)\left[\mathbf{I} + \mathbf{D}_{r_j}(t)\right]\mathbf{p}(t) \tag{5.53}$$

With $\mathbf{B}$ and $\mathbf{A}$ the matrices describing the technology, with, respectively, inputs and outputs coefficient for the n commodities (in columns) used in the n processes of production (in rows) during period of production T, $\mathbf{p}$ the column vector of prices, and $\mathbf{D}_{r_j}$ the diagonal matrix having in its main diagonal the n absolute rentsr_j for each commodity j.

We can then represent system 5.53 under the following form:

$$\begin{bmatrix} b_{1,1} & \dots & b_{1,n} \\ \vdots & \ddots & \vdots \\ b_{n,1} & \dots & b_{n,n} \end{bmatrix}(t) \begin{bmatrix} p_1 \\ \vdots \\ p_n \end{bmatrix}(t+1) = \begin{bmatrix} a_{1,1} & \dots & a_{1,n} \\ \vdots & \ddots & \vdots \\ a_{n,1} & \dots & a_{n,n} \end{bmatrix}(t) \begin{bmatrix} (1+r_1) & & 0 \\ & \ddots & \\ 0 & & (1+r_n) \end{bmatrix}(t) \begin{bmatrix} p_1 \\ \vdots \\ p_n \end{bmatrix}(t) \tag{5.54}$$

Perrings starts from a set of initial prices, and then study the necessary conditions on the distribution variables and the technology in order to stabilize the price vector, i.e. the necessary conditions under which the "system can converge to an equilibrium rate of growth" (Perrings, 1987).

With a stable technology, if there is a uniform rate of rents on all processes, Perrings shows that the price system is stable only if this uniform rate is equal to the physical maximum rate of surplus R (relative prices are stable in the absence of joint production if the uniform rate of surplus is between 0 and R).

If the rates of rents are not uniform, but stable in time, the stability of the price system is ensured when the price vector is an eigenvector of the socio-technical matrix $\mathbf{B}^{-1}\mathbf{A}\left[\mathbf{I}+\mathbf{D}_{r_j}\right]$ (Perrings, 1987, p. 74). But as a result of hypothesis 2, the rates of rents may at the same time be non-uniform and non-constant in time.

In order to demonstrate this, Perrings links the rate of rent of a resource to the excess demand on this resource. Excess demand is the difference between the demand and the quantity produced of the resource; then the rate of rent increases if the excess demand is positive, and *vice versa* (Perrings, 1987, p. 75). Let $\mathbf{q}_E$ be the line vector of excess demand, system 5.53 becomes:

$$\mathbf{Bp}\left(t+1\right)=\mathbf{A}\left[\mathbf{I}+f\left(\mathbf{q}_E\left(t\right)\right)\right]\mathbf{p}\left(t\right) \tag{5.55}$$

This system can only engender a price stability if the excess demand vanished in the long run:

$$lim_{t\to\infty}\mathbf{q}_E\left(t\right)=lim_{t\to\infty}\mathbf{q}\left(t\right)\left[\mathbf{A}-\mathbf{I}\right]=\mathbf{0} \tag{5.56}$$

However, this stability of the price system is not possible if environmental resources and processes are introduced, as the hypothesis of a time-independent technology cannot hold anymore. Without free gift and free disposal, inventions and innovations are needed.

Now arises the question on the existence of free gift and free disposal, a question we can restate as: why is there no price on environmental resources? According to Perrings, there is value when there is property. If there is no value on a resource used by the production system, then there is an exaction: there is no recognition of any property rights on this resource. But this ownership is not just a claim in Perrings system: there can be a rent only if the resource is owned, but also valued, i.e. if the process of production of that resource uses at least one positively priced resource. As Perrings states it:

> "resources are economically scarce [and thus receive a price] when their utilization in the process of a human economy implies the commitment of positively valued resources to secure their possession. The term possession has a very precise meaning here. The commitment of positively valued resources to the exaction of environmental resources implies that the latter are possessed and so endowed with value" (Perrings, 1987, p. 80).

Hence the terms "production" and "process of production" come with a special meaning in Perrings: for instance, labor force is *produced* through the consumption of priced commodities by workers. Thus the wage depends on the claim of the wage earners about the sharing of the surplus but also on the level of consumption goods required for the process of production of labor. A natural resource is produced when there is a need to buy some resources to ensure its protection. The level of the rent on that resource depends on the claim from the owners on the sharing of the surplus and on the required level of protection.

It means that for Perrings, a resource is endorsed with value only when it is appropriated and produced: in his system, labor and natural resources only if some consumption is necessary in order to ensure their reproduction.[40]

Hence prices reflect claims about rights of ownership and costs induced by these rights of ownership. However, prices do not reveal externalities, because externalities are related to exaction or insertion, i.e. to the non-recognition of ownership rights:

> "an environmental effect may accordingly be defined as the change in the value of the outputs of a given economic process or processes resulting from a quantitative or qualitative change in the inputs exacted from the environment by the process(es) due to exactions on or insertions into the environment by the same or some other process(es)" (Perrings, 1987, p. 84).

He considers in that sense that markets are incomplete if they do not consider the protection costs on environmental resources: for him, this lack of consideration is the source of negative externalities concerning the environment, for instance the over-exploitation of natural resources (Perrings, 1987, p. 91).

Perrings thinks that the solution lies in a stationary state of the economy, where the growth rate of the economy is equal to zero (Perrings, 1987, p. 141). The overall economic production would remain stable, but the sectoral productions could vary, as well as the prices. Decisions on the exploitation rate and the pollution of natural resources should be socially decided, because it is a matter of ethics, before being a matter of profits. The price system is thus not the good signal to manage environmental problems: the goal should be to use environmental signals to limit interactions with the environment instead of trying to control everything. Quotas of extraction, a solution advanced by Daly in his description of a steady state economy (Daly, 1992), could be a solution.

5.2.2.3 Discussion

Curiously Perrings thinks that in this kind of stationary economy, technological innovation would be lower than in competitive, profit-driven, economy. He justifies that assumption by referring to the old societies which, for him, were not innovative enough to be resilient in case of environmental catastrophe. This assumption, related to the widespread thinking that pre-capitalist societies were not efficient in the use of their capacities, is criticized by Burkett:

> "Perrings [has an] impoverished conception of how pre-capitalist economies regulate their exactions from nature. He treats their individual sub-units as homogeneous, self-sufficient, and uninnovative. In the real world, we find that pre-capitalist systems have developed a variety of common property devices internally tailored

[40]On the contrary, Lipietz, for instance, considers that a rent can arise as soon as ownership is claimed, without the need for any consumption linked with this ownership (Lipietz, 1979)).

> to the variegated natural environments on which they depend for their reproduction. Often, as these devices have been passed down from one generation to the next in culturally embedded ways, they have been consciously developed to enhance communities' ability to live and prosper with nature" (Burkett, 2006, p. 238, see also Ostrom, 1990).

An other difficulty arises when Perrings, in order to solve the problem of externalities, wants to introduce environmental bonds in order to get a "social control of external effects" (Perrings, 1987, p.164): those bonds would be paid by scarce resource users in order to compensate for the social cost of the irreversible loss, in agreement with the polluter pay principle. The price of each bond will correspond the higher probable social cost. In the same way, for the use of a polluting substance, the user would pay to the society a bond equal to the higher probable social cost. The problem of that solution is of course: how to measure social cost? Perrings explains that the price should be decided socially, but this does not really help. Again this proposal seems to show that the capitalist way of production and distribution is not contested by Perrings.

Finally the whole value approach is said to be inspired by Sraffa's approach, but Perrings makes some assumptions that are not Sraffian. First, Perrings is wrong when he asserts that Sraffa's system is a closed one, that can never contract nor expand (Perrings, 1987, p. 6). The Sraffian model describes a valuation process, not a physical process (this valuation process is of course based on the physical conditions of production, but cannot be reduced to them), and prices at one period of production do not convey any signals about what and how the economy is going to produce in the next period. They just reflect the conditions of production and the distribution of the surplus in that period. Secondly Perrings' system of value is not Sraffian, as prices at the beginning of the period are not the same at the end. Hence prices in Perrings' model depends on initial prices. But how to set this initial prices? This is not known.

Let us come back to Perrings' system of value:

$$\mathbf{Bp}\left(t+1\right)=\mathbf{A}\left[\mathbf{I}+f\left(\mathbf{q}_{E}\left(t\right)\right)\right]\mathbf{p}\left(t\right) \tag{5.57}$$

Prices are cost of production that depends on input prices of the previous period, and on the claim on value added that each resource owner tries to make (rents on resource). This is very far from Sraffa's development as in Sraffa's case, all value added could be related to labor. And then when Perrings links the rent on each resource to the excess demand, we are coming back again on neoclassical tracks, as prices become also dependent on subjective demand. And a difficult question arises: how to measure excess demand?

5.2.3 O'Connor: rent and environment as the origin of basic goods

O'Connor (1993b) continues in the same footing as Perrings (1987), developing an economy-environment model inspired by Sraffa (1960) and Von Neumann

(1946).[41]

O'Connor thinks that:

> "the neo-Ricardian framework can be extended to permit analysis of such questions as the use of irreplaceable natural resources and environmental amenities, and aspects of value system conflicts associated with incompatible uses of such resources" (O'Connor, 1993b).

He focuses on:

> "the use of 'ecological capital', which may be understood to cover stock natural resources, the ecological systems that furnish renewable resource flows and life-support services, and also non-industrial economies that are vulnerable to predation by an expanding modern economy" (O'Connor, 1993b).

This ecological capital may be "unique and irreplaceable" and "not reproducible by industrial processes", and the economy needs this capital in order to produce values. Then for O'Connor, "inevitably ... we see conflicts of interests concerning the appropriation and use of ecological capital". As the economy needs the ecological capital and cannot produce it, it becomes scarce and conflicts arise about its uses.

In order to highlight these conflicts, he builds a neo-Ricardian model of production, representing economic and ecological processes. Joint production is allowed, and each process uses at least one input. The matrices of technology ($\mathbf{A}$ for input, $\mathbf{B}$ for output, both positive matrices) are assumed to be square (same number of processes and resources); processes are displayed in rows, and resources in columns. Fixed coefficient are assumed[42] and only material resources are represented.[43]

He works with a system where environmental and economic processes are interdependent, but interdependence has not the same meaning as in Sraffa,

[41] However, curiously he starts his work with a definition of scarcity ("a resource or service is defined to be scarce if its use incurs a significant positive opportunity cost for society, either elsewhere or in the future", O'Connor, 1993b), and links that with the fact that environmental resources may have no price (i.e. be "free goods") if they were not scarce. This relation between value and scarcity is actually really neoclassical, and opposed to the view of Sraffa (where it is production which leads to value, not scarcity).

[42] The assumption of constant returns helps to "bring out the force of the key notions of irreplaceability and non-substitutability of ecological capital and allows us to express starkly the idea of value system conflict in resource use and control". Actually, as I think that this assumption is not needed, the sake of simplicity (because O'Connor wants to express the dynamics of the economy-environment system) is the only real reason to use it.

[43] As in Perrings (1987) (and some others authors like Patterson, 1998), there is, in O'Connor, a need to represent all physical exchanges, and to relate values to these physical exchanges. However, in Sraffa, value is connected to the exchange of marketed goods and services between agents, thus it is not necessarily related with material exchanges (a service sector, for instance, can be represented in Sraffa, whereas in O'Connor, this sector would use some physical inputs, but would produce nothing).

as there is not always one basic commodity for all processes in O'Connor's examples. The physical system can be represented in this way:

$$\mathbf{y}(T)\,\mathbf{B} = \mathbf{y}(T)\,\mathbf{A} + \mathbf{s}(T) \tag{5.58}$$

With $\mathbf{y}(T)$ the line vector of processes activities and $\mathbf{s}$ the line vector of the surplus. The available quantity at the beginning of the period of production is thus:

$$\mathbf{q}(T) = \mathbf{y}(T)\,\mathbf{A} \tag{5.59}$$

And at the end of the period:

$$\mathbf{q}(T+1) = \mathbf{y}(T)\,\mathbf{B} \tag{5.60}$$

If there are no free gift and no free disposal, then the produced quantity at the end of the period is equal to the quantity used in production in the beginning of the next period, that is:

$$\mathbf{q}(T+1) = \mathbf{y}(T+1)\,\mathbf{A} \tag{5.61}$$

$$\mathbf{q}(T+1) = \mathbf{y}(T)\,\mathbf{B} = \mathbf{y}(T)\,\mathbf{A} + \mathbf{s}(T) = \mathbf{y}(T+1)\,\mathbf{A} \tag{5.62}$$

Hence depending on the initial activity vector, quantities in the surplus vector $\mathbf{s}$ are positive or negative. Quantities of the different resources and activity levels of the different processes will then increase or decrease from periods to periods. At one point, it is possible that they become negative: it means that the system have broken down. Thus "feasible time paths for the ensemble are restricted to non-negative solutions for a sequence $\mathbf{y}(T)$, $\mathbf{y}(T+1)$, ..." (O'Connor, 1993b).

O'Connor does not only want to analyze feasible paths, but furthermore paths that allows for a "balanced growth" (O'Connor, 1993b), in reference to Von Neumann's model (1946), i.e. with a uniform rate of growth for all processes.[44] Mathematically, the following constraint is then added:

$$\mathbf{s}(T) = g\mathbf{y}(T)\,\mathbf{A} \tag{5.63}$$

With g the uniform rate of growth. System 5.58 can be, now, written in this way:

$$\mathbf{y}(T)\,\mathbf{B} = (1+g)\,\mathbf{y}(T)\,\mathbf{A} \tag{5.64}$$

Hence the activity vector $\mathbf{y}(T)$ must be a eigenvector of matrix $\mathbf{AB}^{-1}$.

By considering a global system where natural resources are in limited supply, the available quantities in the beginning of the period of production T are

[44]In Von Neumann's approach, the difference with O'Connor is that there are no scarce resources (all natural resources are "free goods") and there is "free disposal" (if there is excess production, the price is set to zero).

only the ones produced at period $T-1$. Constant growth of the economic subsystem can then only be fulfilled by a decreasing activity of other subsystems : "balanced *growth of the economy* will then mean proportional growth from one period to the next of the *subvector of those resources valued by economic proprietors.* The ensemble activity may then be 'unbalanced"' (O'Connor, 1993b). And constant growth of all the system is not possible (g must be equal to 0, see O'Connor, 1993a for a discussion on Spaceship earth models, with an account of matter and energy flows).

As regards the price system, O'Connor first assumes that there is only one rate of profit, allowing for a "balanced economic expansion" (O'Connor, 1993b). This assumption is not related to the interdependence of all processes, but to the economic competition between processes (in a Von Neumann's way). The price system is thus written as follows:

$$\mathbf{Bp} = (1+\pi)\,\mathbf{Ap} \tag{5.65}$$

5.2.3.1 First example

In a very simple example with two processes, O'Connor represents the economy as a single process producing a non basic good 1, and the environment as a single process which produces a basic good 2. He thus takes the opposite view as the one of Sraffa (1960), who represents natural resources as equivalent to non-basic goods, because there are not produced by the system. In the O'Connor's system, then environment is produced *and* is the support of human activities. The input output representation is thus, with the first process the economic one, and the second the environmental one:

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} \\ 0 & a_{22} \end{bmatrix};\ \mathbf{B} = \begin{bmatrix} b_{11} & 0 \\ 0 & b_{22} \end{bmatrix} \tag{5.66}$$

According to O'Connor, there are then two solutions for the price system 5.65, as matrix $\mathbf{B}^{-1}\mathbf{A}$ has two eigenvalues. These two solutions leads to two different sets of prices and two different rates of profit. The first eigenvalue is equal to:

$$\lambda_1 = \frac{a_{11}}{b_{11}} = \frac{1}{1+\pi_1} \tag{5.67}$$

With $\pi_1 = (b_{11} - a_{11})/a_{11}$ the own-growth rate of the economic good. The price solution is $[p_1 = 1;\ p_2 = 0]$ when π_1 is the chosen uniform rate of profit. The second eigenvalue is equal to:

$$\lambda_2 = \frac{a_{22}}{b_{22}} = \frac{1}{1+\pi_2} \tag{5.68}$$

With $\pi_2 = (b_{22} - a_{22})/a_{22}$ the own-growth rate of the ecological good. If π_2 is the chosen uniform rate of profit, then both prices are strictly positive if $\pi_2 < \pi_1$. If this is not the case, we are in that special case treated by Sraffa as the beans problem (Sraffa, 1960, Appendix B): process 1 uses to much of his own product as an input to be able to produce the same rate of profit as process 2. Hence if we want both prices to be positive, the rate of profit of process 1 should be lower than π_2.

According to O'Connor, the choice between these two solutions is a matter of "value system contest", i.e. the result of a struggle between owners of the two processes. In O'Connor terms,

> "suppose now that each of processes 1 and [2] represents activity managed by distinct societies, each proprietor of their own 'capitals'. Let process 1 be a 'modern' industrial economy geared to expansion and let process [2], the para-economy, be a 'traditional' society geared to self-reproduction. The economy depends absolutely on obtaining inputs of ecological capital. The proprietors of the modern economy might, to ensure positive or at least non-negative value growth, rely on one of two strategies: (i) *force majeure*; or (ii) success in inducing the proprietors of the traditional para-economy to 'alienate' their capital (resource [2]), and to allow it to be used in the service of economic capital accumulation" (O'Connor, 1993b).

His point is that each solution represents a way to capitalize nature. The first solution is the "free goods" solution: the environmental good is extracted without any compensation. In this case, O'Connor shows that to represent in the value system only the economic good, or to represent both goods, but with π_1 as the uniform rate of profit, leads to the same result in terms of valuation. The second solution represents also a capitalization of the ecological process as the ecological good becomes a commodity and a part of a capitalist system of production and accumulation.

Both solutions for the valuation of the goods do not have any relation with the sustainability of the system. On the physical side, there can be a uniform rate of growth g with strictly positive activity levels of both processes only if $g = \pi_1$ and $\pi_1 < \pi_2$. If there are no free goods allowed and no free disposal, it means that $\pi_2 = 0$ and $\pi_1 = 0$, thus the only sustainable vector of activity level would be $[y_1 = 0; y_2 = 1]$.

But what would Sraffa say about this example? According to Sraffa, the only rate of profit that we can calculate is the standard one (i.e. maximal rate of profit of the system, as there is no wage) and it is obtained through the construction of the standard system, i.e. through the elimination of non-basic processes. The standard rate of profit is thus π_2, and prices can be calculated. Sraffa's method would then come up with a unique set of prices. Hence I do not agree with O'Connor when he identifies 'free gift' with 'force majeure', i.e. with extraction without consideration of the rights of local communities: "Force majeure requires no further explanation. Formally it is represented by ... appropriation of the ecological capital as a 'free gift"' (O'Connor, 1993b). He talks about 'force majeure' when the price of nature is set to zero, where this is actually a requirement of the value system of Sraffa.

Furthermore free disposal does not mean that there is not any norm on pollution. Let us for instance look at this sentence from the introduction of a non-published article from 2009: "Investigations of longrun sustainability of joint ecological-economic systems highlight the pertinence of reconsidering 'free disposal' assumptions that underpin Sraffian and von Neumann approaches to value and growth theory" (O'Connor and Andrew, 2009). Besides the confusion between von Neumann and Sraffa's approaches, there is a confusion in the meaning of the theory of value: should it be sustainability values, or conditions of production and distribution values? The first option leads to neoclassical concepts of value, and to the valuation of nature, the second to the Sraffian exchange value concept.

However, the question of O'Connor is relevant: what if the price of a resource is imposed? This is effectively done when one does not represent the ecological good in the matrices of technology.[45] This could also be done when one dominant industry forces its suppliers to lower their prices, and thus to lower their rate of profit. This relates to the question of the relation between Sraffian prices (or accounting prices) and what is actually observed in reality.

5.2.3.2 Second example

O'Connor then looks at the treatment of waste: in his second example, the economic processes does not need the ecological good anymore, but jointly produces a waste (good 3) with the economic good 1. A new process 3 appears in order to dispose of this waste, through use of the waste and the ecological good as inputs. The input output representation becomes:

$$\mathbf{A} = \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & a_{32} & a_{33} \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & b_{13} \\ 0 & b_{22} & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{5.69}$$

Looking at the system 5.65, he finds again that there are only two possibilities for a uniform positive rate of profit, π_1 and π_2. The first solution is again associated with a strictly positive price only on the economic good: $[p_1 = 1; p_2 = 0; p_3 = 0]$. It can mean again that there is a forced free disposal imposed by the dominant economic sector. The second solution can lead to a price vector where p_1 and p_2 are strictly positive, but p_3 is negative. This negative price is not a problem for O'Connor as the good 3 is a waste.[46] This solution again is interpreted by O'Connor as an example of "coercion by the economy over the para-economy, where the latter's proprietors are making the best of a situation they did not choose to enter" (O'Connor, 1993b).

What would Sraffa say about this example? First there is no interdependence between all processes: there are two basic goods (the economic good

[45] This raises the following question: who is the person writing the equations? The question about the valuation process arises here.

[46] We can find the same logic with a negative price attached to a waste in Kurz and Salvadori (1993).

and the ecological good), but neither the economic process nor the ecological process need the other to operate. Only the waste disposal process needs both processes to operate: but as this process does not produce anything, it is a non-basic process. System 5.65 shall not therefore be used in this case: the economic process operates with the profit rate π_1, the ecological process operates with profit rate π_2 and there would be no numeraire to express the exchange ratio between the economic and the ecological goods. An arbitrary exchange ratio must be decided before calculating the price of the waste, knowing that the waste disposal process operates at a profit rate equal to zero, because "the net value of inputs in process 2 is zero by construction" (O'Connor, 1993b).

This last process should not be represented like this, anyway: what is produced by the waste disposal process is "the service of waste disposal". System 5.69 should then be represented in this way:

$$\mathbf{A} = \begin{bmatrix} a_{11} & 0 & a_{33} \\ 0 & a_{22} & 0 \\ 0 & a_{32} & 0 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{13} \end{bmatrix} \tag{5.70}$$

Like this, the waste disposal process produces a service that can receive a positive price, and the owner of that process can receive a positive rate of profit.[47] And we thus come back to the problem of the first example, where the economic and the waste disposal processes are non basic and the ecological process is basic: we accordingly find the same results.

5.2.3.3 Third example

Finally O'Connor looks at the general case where rates of profit are different depending on the processes. This is for him justified as:

> "both the definition of what shall be the prevailing value system and the distribution of any 'surplus value' defined in terms of this system, will depend on outcomes of a military and/or political process ... In general, the outcomes of this political process will remain somewhat indeterminate and there will continue to be evidence of several wholly or partially overlapping, unreconciled, more or less incompatible value systems. Profit equalization is a most implausible outcome of such a power struggle and to assume it obscures the underlying conflict" (O'Connor, 1993b).[48]

[47]This misrepresentation can be interpreted as a desire to represent physical exchanges between industries, where Sraffa's system is actually designed to represent exchanges of marketed commodities and services. Both flows does not always correlates. This wrong logic is close to the attempts to represent ecological prices from Sraffa's methodology (for instance we can find the same kind of mistakes in Patterson, 2002).

[48]He also justified this approach by referring to Perrings, who argues that "an assumed high degree of complementarity of resources means that there is no mechanism to ensure the equalization of returns to all factors" (O'Connor, 1993b). But actually interdependence between processes can ensure that a uniform rate of profit will emerge, even if inputs are complementary.

The value system becomes now:

$$\mathbf{Bp} = (\mathbf{I} + \mathbf{\Pi})\,\mathbf{Ap} \tag{5.71}$$

With $\mathbf{\Pi}$ the diagonal matrix having in its main diagonal the different rates of profit; unlike Perrings (1987), he assumes that the owners of similar processes (and not the owners of similar resources) are the ones likely to join forces into one class. This representation is clearly close to mark-up pricing as represented in some post-Keynesian works (e.g. Lavoie, 1996, see also Kemp-Benedict, 2014, section 5.3.2); then again we come back the question of the relation between the natural prices and what is actually observed in reality. The difference may lie in the rents that everybody tries to capture. According to O'Connor, "the rate(s) of return and relative prices that *actually* prevail can be thought of as kinds of distributional parameters indicating the outcome of the contest over purposes of productive activity and over appropriation of the surpluses" (O'Connor, 1993b, emphasis added). In his examples, they should be seen as "an indicator of the intensity of dominance exercised by the economy over the para-economy, or *vice versa*" (O'Connor, 1993b).

In a last example, he complicates further system 5.69 by adding a fourth resource, an ecological waste produced by the ecological process, and a fourth process, disposing the ecological waste through the use of the economic good. We find again the same problems as in the second example: O'Connor claims that processes are interdependent where actually the system is composed of two independent sub-systems (the economic and the ecological), with two non-basic processes in between:

$$\mathbf{A} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ 0 & a_{22} & 0 & 0 \\ 0 & a_{32} & a_{33} & 0 \\ a_{41} & 0 & 0 & a_{44} \end{bmatrix};\ \mathbf{B} = \begin{bmatrix} b_{11} & 0 & b_{13} & 0 \\ 0 & b_{22} & 0 & b_{24} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{5.72}$$

And again the two processes of waste disposal produce nothing, when the logic of Sraffa would command to represent them as producing services, in the following way:

$$\mathbf{A} = \begin{bmatrix} a_{11} & 0 & a_{13} & 0 \\ 0 & a_{22} & 0 & a_{24} \\ 0 & a_{32} & 0 & 0 \\ a_{41} & 0 & 0 & 0 \end{bmatrix};\ \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix} \tag{5.73}$$

We would then get a system with interdependent processes, and four basic goods. Thus only one rate of profit is possible. Ironically this example is used by O'Connor to investigate precisely what happens when different rates of return apply. He founds that those rates of profit can signal "outcome of the struggle over the reciprocal imposition of a waste-disposal burden" (O'Connor, 1993b).

O'Connor analysis goal is to understand how nature is capitalized. This process may include rewards for the ecological production, but in any case there is no connection between capitalization of nature and increase in sustainability: "if the picture painted by our model has plausibility ... economic progress may not be sustainable value growth under any interpretation" (O'Connor, 1993b). Furthermore he underlines in conclusion that "there is no 'general' treatment of economy-environment dynamics once the features of irreplaceable and/or depletable resources and of value system contest are introduced" (O'Connor, 1993b): indeed, the relations between societies and their environments have always been complex and variegated.

5.2.4 Martinez-Alier

Martinez-Alier (1995) is interested into distributional issues, i.e. how the wealth created by the economy is distributed among classes of population and among nations. He claims that the main concern of political economy is distributional conflicts. One famous (theoretical) distributional issue is what is called "the internal contradiction of capitalism":

> "firms are individually inclined not to pay high wages, and therefore there might be a lack of effective demand from households in the aggregate to buy all the goods and services which would be available with production running at full capacity utilization" (Martinez-Alier, 1995).[49] [50]

Distributional conflicts in relation with the environment can be separated in three classes: first there are conflicts around the distribution of natural resources, then around payment for environmental damages and then there are problems about the accounting of the needs of future generations.

On the first type of conflicts, one has to remember that everything has a price if someone asks for it. If we are looking at produced goods, workers and capitalists ask for a price, the firsts in order to be paid for the labor time,

[49]This contradiction is also described by Castoriadis (1979): "le capitalisme, au contraire [des formes sociales qui l'ont précédé], est bâti sur une contradiction intrinsèque – une contradiction vraie, au sens littéral du terme. L'organisation capitaliste de la société est contradictoire au sens rigoureux où un individu névrosé l'est : elle ne peut tenter de réaliser ses intentions que par des actes qui les contrarient constamment. Pour se situer au niveau fondamental, celui de la production : le système capitaliste ne peut vivre qu'en essayant continuellement de réduire les salariés en purs exécutants – et il ne peut fonctionner que dans la mesure où cette réduction ne se réalise pas ; le capitalisme est obligé de solliciter constamment la participation des salariés au processus de production, participation qu'il tend par ailleurs lui-même à rendre impossible" (cited in Boltanski and Chiapello (1999)).

[50]A second contradiction of capitalism is described by James O'Connor (1994a): the accumulation process leads to produce more with lower costs, but the environment cannot endlessly give us cheap resources. Ecological processes of production follow their own rhythms and if resources become more scarce, it will be more costly to extract them. Thus their prices could increase, leading to a second contradiction. However, this is conditional, because it depends on distributional issues: the allocation of property rights and the allocation of income, between present and future generations.

the seconds because they are the owners of the goods. If we look at natural resources, then there is no worker asking for a reward, but there still can be owners to ask for a price on the use of the resource (or to ask for compensation if the resource has been destroyed): for example the rentier who asks for a rent on his land. Then arises the question of the allocation of property rights on nature. This allocation is always the result of a political process, and it could be the result of a democratic deliberation or of a violent conflict (i.e. it is also the result of power relationships). And of course some natural resources and services are not allocated. The question Martinez-Alier asks is: who is willing to take care of these resources? For instance:

- "Are there owners of the Earth's ability to recycle a good part of the CO_2 pumped by humans into the atmosphere?"
- "Are there owners capable of evaporating water and making it fall again in places where water is scarce?"
- "Are there owners of wild and agricultural biodiversity, partly yet uncatalogued?" (Martinez-Alier, 1995).

Here Martinez-Alier is not saying that all natural resources and services should be privately owned, but rather that people and companies that are destroying these resources are acting as if they were their owners. Hence there is a need for someone to say: "this is not your property" or "this is also my property, and the property of my children", so a discussion about the protection or not of the resource can start:

> "For instance, we Europeans pay nothing for the environmental space we are using in order to dispose of our emissions of CO_2... Valuation of externalities depends on the allocation of property rights. In this case, the Europeans acts as if we owned a sizable chunk of the planet outside Europe, but (almost) nobody is yet complaining, or trying to charge us a fee" (Martinez-Alier, 1995).

The second type of distributional conflicts concerns the level of the payment if a natural resource has been destroyed (how to value externalities). This level of payment also depends on distribution of income. "The poor sell cheap" principle, or "Lawrence Summers' principle" (Martinez-Alier, 1995) tells us that:

> "the measurement of the costs of health impairing pollution depends on the foregone earnings from increased morbidity and mortality. From this point of view a given amount of health impairing pollution should be done in the country with the lowest cost, which will be the country with the lowest wage" (Summers, 1992, cited in Martinez-Alier, 1995).

An application of this principle can be found in the Texaco vs. Ecuador case, where:

> "Texaco was involved in the extraction of oil from the northern part of the Amazonian territory of Ecuador since the early 1970s until 1990. Damages [arisen] from oil spills, deforestation, disruption of the life of local indigenous communities".[51]

In the beginning of this case, the following question arose: should Texaco-Chevron, a US company, pay the US price for damages, or the Ecuadorian price? As Ecuadorian were a poor people, Texaco asks for an out-of-court settlement: "the out-of-court settlement being discussed in the fall of 1994 ... seemed to imply a payment by Texaco of about ... one hundred time less than the damages being sought in court" (Martinez-Alier, 1995).

And finally arises the question of the distribution of ownership and income between generations. If there are irreversible damages, should we take into account the use value which is lost? In this case, what discount rate may apply? Martinez-Alier refers to a "fair" positive discount rate when there are expectations about an increase of the technological capacity of production with the same (natural) capital: "investment sometimes increases productive capacity" (Martinez-Alier, 1995). Hence future generations may produce the same amount of wealth with less natural capital and this is why we may value the future use less than the present one, and thus consume now part of the natural capital. But of course investment sometimes destroys natural productive capacity, and thus it is not easy to know if future generations will produce enough wealth with enough natural capital. And it is not because we have found the just discount rate that the value of the initial capital is fair.[52]

Furthermore, we could take into account, besides the future use value, an option value (the resource is not yet used, but could be in the future) and an existence value (the resource has an ethical right to exist). This last item is interesting because it enlarges the scope of distributional issues: for instance, "the Texaco case provides example of attempts to put present money values to the unknown loss of biodiversity" (Martinez-Alier, 1995). Here the problem becomes: how can it be possible to put a value on something which has no connection to any economic activity? Economic value express the utility for society of a given thing, or the fact that this thing has been appropriated by someone; but in the case of existence value, there are no such relations. It is not then possible to apply an economic method (like the Sraffian one) to find the existence value of an object. This is the issue of incommensurability: the

[51] The case is still under consideration: in 2011, a independent Ecuadorean court ordered Chevron (the new owner of Texaco) to pay \$9.5 billion, but in 2014 the U.S. District Court for the Southern District of New York finds that the Ecuadorian judgment was unenforceable.

[52] This question on the discount rate relates to the question of the "just" or natural rate of interest investigated by Pasinetti (1993; 2001). According to him, the rate of interest should be a rate "which maintains unaltered through time the purchasing power of all debt/credit relations in terms of labor" (Pasinetti, 2001). Why in terms of labor? Because this is a unit of value (time spent doing work) which is not supposed to change through time. Hence when a lender gives to an investor the money he won during one hour of work, he shall be able to receive in the future the equivalent of one hour of work. And if the investment increases the productive capacity, then he shall receive more money than what he lent, because one hour of work has become more productive.

measure of economic value does not apply to every items. However, even if there is not a common unit of measurement, "it does *not* mean that we cannot compare alternative decisions on a rational basis, on *different* scales of values, as in multicriteria evaluation" (Martinez-Alier, 1995).

In the Texaco's example, the price depends on the income of the owner, i.e. on income distribution. This relation between price and distribution of income is not the same in neoclassical and Sraffian economics. In neoclassical economics, prices and distribution are simultaneously give, and income is the result of marginal productivities of factors of production (capital, labor, land). In Sraffian economics, income distribution does not depend on marginal productivities, but is a result of a power struggle: once distribution is set, prices can be calculated. This is why Martinez-Alier claims that Sraffian economists are more close to political economy issues than neoclassical economists, because the firsts claim that there is no "true value" of the services of labor, capital or nature (only a political process can assess these values), .

Martinez-Alier remains careful about the possible applications of Sraffian economics:

> "Assuming there would be a Sraffian ecological economics, we would need first to decide which items belong to 'natural capital' (i.e. are appropriated and by whom), and then we could show how their valuation depends on the distribution of income. Sraffian economics (even if 'ecologized') is economics, and therefore it would attempt to explain economic values. It would not deal with the wider issues of 'ecological distribution"' (Martinez-Alier, 1997).

To develop that latter issue, Martinez-Alier calls for the development of a "political ecology", which "would study 'ecological distribution' conflicts" (Martinez-Alier, 1995). According to him, ecological distribution refers to "the social, spatial, and temporal asymmetries or inequalities in the use by humans of environmental resources and services, i.e. in the depletion of natural resources (including the loss of biodiversity), and in the burdens of pollution".

Martinez-Alier does not clarify who are the social actors of ecological distribution conflicts (or of the second contradiction of capitalism described by O'Connor, 1994a). According to him this is not a fight for the appropriation of the surplus within the capitalist mode of production between capitalists, rentiers and workers, as in Sraffian models. It is a fight about "reproduction of human society and of nature's functions"; so for him different actors are involved. The result of such conflict can be seen when a price is set in order to compensate for the destruction of an environmental service: the level of this price expresses the relation of power between the protagonists. One important thing is then to understand what this compensation price can cover, and which language of valuation has been used:

> "Are ecological values only valid if they are translated into financial terms, or are they valid in themselves with their units of biomass and biodiversity? Is it valid to argue directly in terms of

> human health, subsistence and welfare, or do we have to translate them into money? What is the value of a landscape, not in monetary terms, but in itself? How much is human life worth, not in terms of money, but in itself? Hence the question that brings ecological economics and political ecology together: who has the social and political power to simplify complexity and impose a particular language of valuation?" (Pellegrini, 2012).

5.2.5 Douai

Ali Douai (2009) considers that the classical theory of production prices developed by Ricardo and Marx can be useful to ecological economics. According to him, the classical theory makes the distinction between the use value and the exchange value, and thus between the wealth (the sum of use values, etymologically defined by Douai as the conditions of well-being) and the economic production (sum of exchange values). Hence, because it acknowledges the fact that the economy is not aiming (or not uppermost aiming) at satisfying human needs, but at capitalistic accumulation instead (through economic production), leading to the possibility of bad social and environmental consequences, this theory appears more appealing than the neoclassic theory which, following Say, aggregates wealth and economic value into the same unit: "the key idea - which Marx and Engels [Marx and Engels, 1975] attributed to Bentham - is that 'money represents the value of all things, people and social relations"' (Douai, 2009).

The problem is that the monetary vision of wealth is dominant, because the neoclassical theory is dominant. Until now, ecological economics have only underline that different systems of value could coexist, that it is not ethical to reduce them to the sole economic value system (problem that occurs in neoclassical Willingness to Pay/Willingness to Accept studies) and that we should build "discursive" institutions allowing the society to solve the problem of non commensurable systems of value. But classical economics could help to go further, by fighting directly the neoclassical vision. Ricardo for instance asserts that:

> "[utility] is certainly the *foundation* of [exchange value], but the degree of utility can never be a measure by which to estimate [exchange value]. A commodity difficult of production will always be more valuable than one which is easily produced although all men should agree that the latter is more useful than the former" (Ricardo, 1973, cited in Douai, 2009).

According to Ricardo, if water would become suddenly a marketed good, with a price (through the private appropriation of the water by a rentier), this would not rise the national wealth: the economic production would not increase and the surplus would then be the same. This rent is not connected to a phenomenon of differential rent or production, and then cannot be calculated through Ricardo's (and Sraffa's) system; but as soon as this rent is assumed in an exogenous way, it will impact the price system (and all prices if water enters into the composition of a basic good); the maximum rate of profit will not move but the shares of the surplus devoted to the profits and to the wages will be lowered. Thus national wealth would not increase: it would just be distributed in a different way. The Ricardian analysis allows then to distinguish between variations of wealth and variations of price, and this leaves a room for the non-monetary evaluation of goods producing use value for humans.

Ricardo defines utility as "the capacity of things to meet the *'necessities, conveniences, and enjoyments of human life'*" (Ricardo, 1817, cited inDouai, 2009). He is in opposition with Say's definition (Say, 1972) of political economy:

> "Political Economy [Say] thinks is an enquiry into the nature and causes of wealth; I think it should rather be called an enquiry into the laws which determine the division of the produce of industry amongst the classes who concur in its formation" (Ricardo, 1817, cited in Douai, 2009).

Wealth cannot be reduced to a quantity of exchange value; thus for Ricardo political economy should be more modest and concentrate its efforts in the understanding of economic production and distribution.

We find again this dichotomy between use value and exchange value in Marx. The first is defined qualitatively and is dependent on the social context, it cannot be considered as an economic category. The second is defined quantitatively as the quantity of abstract labor needed to produce the good. There is social validation of concrete labor and thus its transformation into abstract labor when there is exchange with the help of money. Wealth, on the contrary, is not necessarily connected with a quantity of labor: use value, the component of wealth, can come from human labor, but can also be separated from it, and in the first case this human labor can be economically validated or not (it can remain only concrete or become also abstract). As states Marx:

> "[one thing] can be a use-value, without having [economic] value. This is the case whenever its utility to man is not due to labor. Such are air, virgin soil, natural meadows, etc. A thing can be useful, and the product of human labor, without being a commodity. Whoever directly satisfies his wants with the product of his own labor creates, indeed, use-values, but not commodities" (Marx, 1867, cited in Douai, 2009).

The problem of capitalism is that it is aiming at the infinite accumulation of exchange values, and only exchanges values: thus there is a pressure to connect all notions of wealth with exchange value, so that all exchanges becomes monetary exchanges. This creates social troubles (true use values becoming less considered) and environmental troubles (again because goods which are not associated with an exchange value are not considered useful anymore). This ambivalent relation between the accumulation of exchange values and the production of use values has been well described by Marx: the production of use value becomes “an unavoidable intermediate link [...], a necessary evil for the sake of money making” (Marx, 1976, cited in Douai, 2009). According to Marx and Engels this type of reverse reasoning is more and more common because of the development of utilitarian thinking.

Douai summarises the problem about money as an account of wealth in this way:

> “the possibility of seeing the value of all things, people and social relations in terms of money is *specific to capitalist conditions*. What utility theory does not say is that money is the material expression of the social character of production and not of utility. When money becomes the general expression of wealth, it expresses: 1) a power: ‘that each individual exercises over others’ activity or over social wealth exists in him as the owner money. Thus both his power over society and his association with it is carried in his pocket’ [Marx, 7 68]; (2) the effacement of all natural and human qualities” (Douai, 2009).

From there Douai criticizes ecological economics researchers who agree on one hand with the attempts to give an economic value to an environmental good or service with the help of the neoclassical theory (value of a marginal unit, contingent valuation, WTP/WTA studies, etc.) and on the other hand who highlight the limits of these studies by showing that all systems of value are not taken into account. Indeed, they are not, because the goal of the neoclassical theory of value is to express use value with money: it takes for granted that there is a commensurability of *all* systems of value into money (in order to answer the question how is this good useful to society, it reduces the question to: how much this good is useful to society). It is not possible to support both position without contradiction. Hence Douai wants that ecological economists take a more critical stance on the economic valuation of nature, keeping in mind that: “economic value (as its monetary form) is an expression of social relations that are exclusively characteristic of capitalism” (Douai, 2009). He is not saying that nature cannot be a support for economic value creation but that nature has no intrinsic economic value.[53]

Douai then criticizes Cost Benefit Analysis, who uses money in a simplistic way as a mean of exchange and of valuation of the use of an environmental good or service, aggregating the pluralities of values, where money, in fact, reflects social relations and supports a specific value system. We can then, in the light of Marx and Ricardo’s political economy, understand why, simultaneously, some people will accept to give a price to nature (“since it reflects the alienation of social relations and relations with nature from their real meaning”, Douai, 2009)

[53]He also highlights that scarcity can be a source of economic valuation, following Marx: “for Marx, scarcity is also a condition of economic value” (Douai, 2009). He then adds: “[ecological resource] scarcity and usefulness are necessary pre-conditions [to support the production of economic value for capital]”. Here scarcity should be understood as *scarce enough to allow for appropriation*. Following Lipietz (1979), we can say that scarcity exists as soon as someone privately owns the resource and then decides who should make use of it.

and why others will refuse ("they may associate economic value/money with specific interests or positions in bourgeois society and/or see it as representative of the negation of any specific quality", Douai, 2009).

However classical political economy does not give any clue about the way we could take into account the environment in political decisions (which institutions? which decision models?). And we have to underline that environmental conflicts are not only conflicts of values, but also conflicts of power and interests (O'Neill, 1997). It is thus, for Douai, extremely delicate to promote participative democracy or deliberative democracy as the decision model that anyone should adopt in environmental conflicts (a vision that ecological economists usually support) without first a study of the existing social structures and of the tensions between individual and social values. As Vatn says it: "[power] may be built into the basic structures of society – the institutions – like access to resources ... brute force is transformed into 'the way things are"' (Vatn, 2005). Political economy needs to reveal these power structures before building a fair environmental policy.

5.2.6 Burkett

Burkett, a Marxist, enters into the debate of the valuation of the environment; for him the purpose of the value analysis is not to "explain exchanges values" (as in Farber et al., 2002), but to reveal what are the conditions of production and especially how these conditions of production leads to the exploitation of human labor and the destruction of the environment. He offers a Marxist analysis of value, and of the relation between the economy and the environment. According to him, use-value means utility, i.e. something providing satisfaction is valuable in terms of use-value. Exchange value is the market price of a commodity: under capitalism, this price does not reflect the use-value of this commodity, but in order to be sold, the commodity must have an use-value. The exchange-value, under capitalism, represents the amount of value embodied in it, i.e. the "abstract, socially necessary labor" performed in order to produce this commodity (Burkett, 2006, p. 184). "Abstract" because, under capitalism, labor is made uniform through the wage relation. "Socially necessary" because the commodity has an use-value which is reflected in the fact that the commodity can be sold on the market.

However, saying that capitalism reduces the exchange value to abstract labor does not mean that only labor can creates use-value. Nature is also a source of use-values:

> "Marx ... insists that both nature and human labor contribute to the production of all these use-values. In analyzing commodities and money, he emphasizes that 'the physical bodies of commodities, are combinations of two elements, the material provided by nature, and labor'. Importantly, Marx also insists that 'nothing can be a value without being an object of utility. If the thing is useless, so

> is the labor contained in it; the labor does not count as labor, and therefore creates no value"' (Burkett, 2006, p. 184, Marx, 1976).

In order to be endorsed with an exchange value, a commodity then needs to be produced with the help of labor and nature, and it must generate an use-value:

The concept of exploitation lies in the fact that human labor can produce more than its means of subsistence:

> "for Marx, the possibility of surplus-value stems from labour-power's 'specific use-value...of being a source not only of value, but of more value than it has itself'. ... The result is an energy subsidy for the capitalist who appropriates and sells the commodities produced during the portion of the workday over and above that required to produce the means of subsistence represented by the wage" (Burkett, 2006, p. 191-192, Marx, 1976).

Burkett describes the alienation of the producers from the conditions of production as a condition for capitalism development:

> "This alienated form of exchange only becomes dominant on the basis of workers' three-fold alienation: from necessary production conditions (including the land), from the production process itself, and from its products. Competitive market exchange and monetary valuation are not just matters of 'convenience' in capitalist society. They are necessary social forms of material wealth in a system where workers are socially separated from necessary conditions of production to the point where they must become wage-labourers (work for money) in order to live. ... It is only in this situation that the economy becomes an apparently autonomous, self-regulating sphere vis-à-vis the natural, cultural, and political dimensions of social reproduction and human development" (Burkett, 2006, p. 133).

Hence labor becomes a commodity, and nature as well, in order to allow for the expansion of capitalism:

> "the conversion of human labour-power and natural conditions into capital is not just a way of thinking, not just ideological, not just a legal-juridical construct, and not even just a commodification of the conditions of human existence: it is a fundamental condition (and contradiction) of capitalism at the level of production relations. ... Under capitalism, human labour-power and nature really are socially separate means of competitive profit-driven production" (Burkett, 2006, p. 133-134).

Burkett starts his analysis of the value debate in ecological economics by describing the energy theory of value (Burkett, 2003, Burkett, 2006, chap. 1) as proposed by Costanza, Hannon, Farber and Wilson (Costanza, 1980; Costanza and Neill, 1981; Hannon, 1998; Farber et al., 2002). This approach has been mainly criticized because it assumes that the qualities of all factors of production can be reduced to their energy contents (whereas "matter matters too", Georgescu-Roegen, 1979). Two approaches then attempt to offer an alternative to the energy theory of value within the ecological economics field.[54] First an eco-Sraffian approach (Perrings, 1987; O'Connor, 1993b; Patterson, 2002) uses "Sraffian input-output models to analyze the determination of market exchange values (and related issues of distributional conflict and economic crises), but without treating any single primary input as the unique source of value" (Burkett, 2006, p. 19). A second track tries to link a flow-fund model of production with a theory where exchange value is not connected with one factor of production and where use-value is defined as "enjoyment of life" (Georgescu-Roegen, 1979; Daly, 1992).

Burkett first criticizes the energy theory of value: for him, using Sraffian input-output model to describe natural processes is like assuming that "markets exist for all sources and types of energy used in production including the free solar energy" (Burkett, 2006, p. 38, he follows Daly, 1981 on this point), which is highly implausible. In fact for him the Sraffian description of the economy is only possible in a capitalist economy, where all resources and labor are reduced to exchanged commodities. In his analysis, a non capitalist economy could not be described by the same model: in a non capitalist society, conditions of productions (i.e. resources and means of production) are in the hands of the workers, and labour-power cannot be separated from his conditions of production. Thus there could not be a uniform wage and a uniform price on each resource, and there could not exist a direct connection between money and wealth in such economy.[55] On the contrary, in a capitalist economy, workers are separated from their natural conditions of production, and this separation allows the capitalist mode of valuation to appear:

> "the regulation of social production by the market (the imperative for value to be objectified in salable commodities) is itself based on the separation of producers from necessary production conditions. It is true that markets and money have existed for aeons; but the dominant position of profit-driven commodity production, and the constant competitive pressures on the producers, owe themselves to the commodification of 'free' labour-power and its employment by autonomous enterprises controlling the (now 'separate') conditions of production. The conversion of natural conditions into mere conditions of market- and profit-driven production (either through their free appropriation or through their

[54] There has been also criticism of the energy theory of value from an eco-Marxist point of view, see Skirbekk (1994).

[55] This non-capitalist economy would also value nature differently depending on the different community: "only through a real communality, in which people gain control over the social conditions of their existence ..., will society be able to regulate its metabolic interchange with nature in a healthy and sustainable way" (Burkett (2006), p. 54-55).

> formal capitalisation as rent-yielding private or state property) is, in particular, enabled by the 'freeing' of labour-power from these conditions. This process continues today whenever public or communal lands are privatized, and whenever corporations are given freer reign to exploit national forests and other natural resources" (Burkett (2006), p. 53-54).

As all processes of production need some energy, this is not then very surprising that a correlation is found between exchange value and energy exploitation. As Daly states, and as Burkett repeats, "this is not 'a true empirical founding', but rather an 'imposed result of the analytical framework"' (Burkett, 2006, p. 38, Daly, 1981). But this a dangerous result if it leads to the evaluation of natural ecosystems using market energy prices (Daly, 1981):

> "the energy theory's search for a primary input is driven by its reduction of the question of value to that of finding some common measure of use-value conceived apart from historically specific social relations of production. This decision having been made, it is but a short step to the view that money and markets are just convenient social devices for registering these quantitative 'energy values' as exchange-values" (Burkett, 2006, p. 38-39).

Actually the question is: why are there market prices? Are they fair? If they represents use-value, as for example Farber et al. (2002) argue, then they are fair, and we could use them to value the environment (as there is a correlation between energy use and market prices, and thus between energy use and use-value). However, if they are just the representation of the current compromise in the confrontation to possess a share of the surplus between social classes or/and the representation of the current capitalist way of valuation, then the valuation of nature through market prices should be rejected.

Burkett then criticizes the eco-Sraffian approach (Burkett, 2006, chap. 1 and 8): according to him, again, these models fail to consider the specificity of capitalism, i.e. the reduction of labor and resources into commodities. They think they described reality, but they described a capitalist way of representing reality. This capitalist representation is currently effective in most human economies, but it is not because it is the current state of the economy that it is a fair state and that it has always been the way the economy was regulated. Hence there should not be a need to extend this representation to environmental processes. Furthermore, Burkett adds that:

> "the assignment of monetary prices to ecological use-values, even when they are not priced in reality, complements the 'tragedy of the commons' notion that the non-pricing of natural resources and the non-assignment of private or state property rights to these resources explains why they are overexploited, as well as the companion notion of a 'green capitalism' which fulfills the resource-pricing and property rights functions more effectively" (Burkett, 2006, p. 44-45).

Perrings for instance assumes that the problem of externalities can be solved by using environmental bonds (Perrings, 1987), i.e. a tax that each user of nature resource should pay in order to finance the protection of the resource. Here the problem for Burkett lies also "in the qualitative reduction of natural wealth to *homogeneous* monetary terms" (Burkett, 2006, p. 42, emphasis added). To accept monetary exchange in a particular problem of natural resource exhaustion could be acceptable, but to generalize the result of the valuation of a specific case to all environmental conflicts, this means capitalizing nature. Even if all partners agree on a price for a natural resource, if this price is generalized on a national or a global level, this means a commodification of nature.

Burkett is also opposed to the analysis of O'Connor (1993b):

> "because O'Connor's model lacks a treatment of the industrial economy's internal production relations as relations of class exploitation (it does not even distinguish human labourers from other inputs), it must take this economy's growth imperative as a given. Since the model does not explain this imperative, or how it is related to competition, it cannot explain why rational capitalists ('industrial proprietors') would pursue it to the point of their own destruction, or how they are able to get their employees to follow them down this suicidal path" (Burkett, 2006, p. 255).

Indeed, the social relation of production - the relation between classes - are not explained by O'Connor, and also the dynamics of the system - the reason why there is a need to grow indefinitely - are not clarified.

Burkett deepens this criticism when he talks about the model of England (1986). According to him there are three problems with this generalization of the class struggle between environmentalist, workers and capitalists. First the model does not describe the power relations and how these relations are constructed; second there is apparently a collusion of interest between capitalist and workers against the environmentalist, where in reality things are more complex; third, the model does not allow for a capitalist sector of production producing the service of waste disposal. Stated differently, "the model does not distinguish pollution control for profit versus pollution control for human needs" (Burkett, 2006, p. 275).[56] And this distinction is important as the waste prevention is not a plausible outcome of pollution control for profits; thus pollution control for human needs should be implemented:

> "what is needed is a change in production technology toward greater quality and durability of the goods produced and less total waste generated by production itself. But such a change conflicts with the capitalist imperative to accumulate ever larger quantities of capital through the production and sale of commodities. This is why it can only occur in the context of workers and communities

[56]We find the same problem in O'Connor's representation of the waste disposal sector (O'Connor, 1993b)

> taking control of production and reorienting it toward sustainable human development" (Burkett, 2006, p. 276).

Burkett follows that with a criticism of the approach of Daly and Georgescu-Roegen, although they are not attempting to put a value on nature and they are not using extended Sraffian models to represent the interaction between environment and economy. According to Burkett the problem lies in their uncritical look on capitalism: for them, capitalism has nothing to do with the environmental problems, in the sense that the problem is not how we are producing commodities (what are the conditions of production), but the scale at which we are producing them. However, for Burkett, solving the scale problem (by adding resource-depletion and birth quotas to a capitalist way of production) is a curative solution, not a preventive one: the way capitalism separates producers from conditions of production is the real source of the environmental problems, as well as the source of the problem of human development. And if we are looking at the reproduction of nature and of human society "in a healthy and sustainable way" (Burkett, 2006, p. 53), we must change the scale, but also the way we produce. In Burkett terminology,

> "capitalism is a social form of human-material production; hence it still has material, use-value requirements. But these requirements are obviously quite minimal compared to the requirements of a healthy and sustainable interchange between economy and nature. This is precisely why it is so crucial to analytically distinguish capitalist reproduction from human-natural reproduction in general" (Burkett (2006), p. 53).

Burkett then also runs counter to James O'Connor's two contradictions of capitalism (O'Connor, 1994a),[57] because for him this is the expression of a separation between two problems (distribution of surplus and environmental conflicts) that are actually well linked.[58] It is because workers are separated from the natural conditions of living that they are embedded in a struggle for the appropriation of the surplus and that, at the same time, nature is destroyed and commodified. The fight for human development against capitalism development should then be carried out together by workers and environmental activists, as it solves both contradiction at the same time. Burkett thus solves the question of the identification of the social actors of environmental conflicts raised by England (1986) and Martinez-Alier (1995): all that are fighting capitalism are also the actors of the ecological distribution conflicts.

My point of view is that, on several points, Burkett goes too far into his criticism of Sraffa's models. First, according to him, Sraffa's prices are "long-run equilibrium prices" (Burkett, 2006, p. 221), where I think that they are

[57] The first contradiction appears because the perpetual search for high profits leads to lower wages, which lead to a decrease of the demand. The second contradiction appears because the perpetual search for accumulation leads to the destruction of nature, and then the decrease of production.

[58] He also disagrees with James O'Connor's argument that Marx was not interested in the environmental questions (Burkett, 2006, p. 6).

just the prices of the current period of production. Second he thinks (in part because of the first point) that Sraffa's model is too much capitalist, in the sense that the only possibility for social change is rejected in the distribution of the equilibrium long term surplus: "class conflict [in Sraffian models] is ... relegated to distribution, and can play no role in production" (Burkett, 2006, p. 228). It is true that Sraffa in his book never talks about class conflicts but I think that the result of one period of production says nothing about the conditions of production in the next period. Prices are the result of the conditions of production and of the distribution of the surplus in that period; in the next period both conditions of production and the sharing of the surplus can change. When Burkett asserts that "like neoclassical theory, [Sraffian analysis] throws a technical, ahistorical cloak over the social relations of production and their shaping of the combined exploitation of labor and nature" (Burkett, 2006, p. 229), he therefore goes too far, in the sense that Sraffian models may be silent on the relation of production but are not ahistorical: they explain what has just happened, and say nothing about the future.

Nevertheless it is true that it is possible to use Sraffian models in order to capitalize nature, i.e. conflating natural use-value with capital: I agree with Burkett that this is only acceptable if the goal of the model is precisely to criticize such commodification of nature. And I follow Burkett when he thinks that the fight against capitalism is also a fight for a better human-environment relationship, and when he argues that this was Marx position. This position is contrary to the understanding of Marx from Martinez-Alier for instance: for him Marx was not really interested in environmental considerations. Marx in particular has rejected the theory of Podolinsky, which is one of the precursor of ecological economics thinking (Martinez-Alier and Naredo, 1982). However, Burkett does not agree with this argument, and argues that, if Marx was reluctant to adopt Podolinsky ideas, it was not because he was thinking that the labor was the sole source of value but because Podolinsky wanted to link the theory of value with the use of energy, without clearly understanding that in a capitalist economy value is reduced to human socially necessary labor (see also Harribey, 2014 on this point).

5.2.7 Harribey

Harribey is a Marxist author, not exactly related to ecological economics, but he writes some articles and one book (Harribey, 2013) related to the question of the nature's value, to the theory of value, and to Sraffa's theory. As regards the debate on the value of nature, Harribey makes five proposal (Harribey, 2013, p. 184-185):

1. Natural resources are wealth, i.e. a source of use value;
2. They have exchange values (economic values) only after being processed by human labor (there is no price for oil before it is extracted, for instance);

3. They do not create exchange values, but they are one of the main component of human wealth and of exchange values;

4. The choice to preserve them is an ethic and political choice, referring to non-economic values, that cannot be measured in money terms;

5. The ecological crisis is the result of capitalism tendency of accumulation and appropriation of all sources of wealth.

On Sraffa's theory, Harribey thinks that it is a decisive argument against the neoclassical theory of value and of distribution, as it proves that the result of exchanges alone are not enough to know the prices, the wage and the rate of profit: one of the distribution variable has to be fixed in an exogenous way. Sraffa demonstrates the possibility to calculate the physical rate of surplus and the importance of the conflict between wages and profits for the share of this surplus (Harribey, 2013, p. 106). The value of capital cannot be measured without knowing the result of the surplus distribution. The neoclassical theory states that the existence of a market and the knowledge of the conditions of production and the preferences is sufficient to allocate the commodities in an efficient way, and thus to know the prices and the distribution: but Sraffa shows that the distribution can be known separately from the prices, and then that the problems of the definition of the distribution and the definition of the prices are two separate problems, that can be analyzed separately (the first being the result of a political process, the second a mathematical consequence of the first).

However, for Harribey, Sraffa hides the social relation of production, because he is not talking about the labor value and about the capitalist exploitation of human labor (Harribey, 2013, p. 98). Harribey's theory of value is the following one (Harribey, 2013, 107): human labor is socially approved as producing use value when the commodity is sold on the market (looking at commodities sold on the market, we can write the equations of production). The market and the capitalist competition then ensures that the rate of profit is equalized (thus prices can be calculated). Finally offer and demand influence prices of production, generating the actual real market prices. The capitalist conditions of production reduce the value of each produced commodity to its substance, human "socially approved" labor (Harribey, 2013, p. 114). Hence this theory is a theory of social relationships, before being a theory of prices.

My point of view is that Harribey makes some approximations about Sraffa. First he thinks that the standard commodity, i.e. the commodity solving Ricardo's problem of finding an invariant value when the distribution is changing, is the ultimate result of Sraffa's analysis (Harribey, 2013, p. 97). Actually I think, following Sinha (2009), that this founding is an incident result of Sraffa's analysis, whose ultimate goal was to develop an objective price theory: "it was only when the Standard system and the distinction between basics and non-basics had emerged in the course of the present investigation that the above interpretation of Ricardo's theory suggested itself as a natural consequence" (Sraffa, 1960, Appendix D). Second Harribey thinks, following Husson (Perez, 1980), that the fact that prices are those exchange ratios that allow for the repetition of the production process[59] means that there is an hidden hypothesis that the system should be in a technological stationary state (Harribey, 2013, p. 98). I do not agree on that: Sraffa tries to find the prices that would allow the process to be repeated, just by looking at the physical exchanges during one period of production. He is not looking at what has happened before, and at what will happen after. Thus prices reflect the conditions of production of that period (they are the exchanges ratios that would prevail if one wants to repeat the production) and they will change as soon as a technical change occurs. Sraffa's definition of prices does not suppose any assumption on the dynamics of the system.

5.2.8 Martins

Martins (2013) claims that the classical surplus approach of political economy, showing a revival after the works of Sraffa and Sen (1999), is much more valuable to understand environmental problems than neoclassical economics.

The two approaches first differ from each other about their definition of "human well-being". Well-being is defined in terms of subjective preferences or utilities in neoclassical economics. Well-being increases if the amount of utility delivered by a given amount of consumed goods and services increases: thus well-being is defined *relatively*. If one adopts the view of neoclassical economics, more is always better, which leads directly to the conclusion that "all goods are scarce, since human beings would always want more goods" (Martins, 2013).[60] On the other end, in classical economics and especially in the capability theory developed by Sen, well-being is defined objectively in terms of "objective functionings", i.e. "what a human being is, or does" (Martins, 2013). There is well-being if there is a certain level of "freedom to achieve" basic human functionings. This freedom to achieve is defined by Sen as a "capability" and looking at someone's basic capabilities, it is possible to say objectively (without asking him) if he enjoys a basic well-being or not. Hence the central goals of the two theories are really different: neoclassical economics study the allocation of scarce goods according to subjective preferences, whereas classical economics study how the economic system is able to produce the means of subsistence needed by everybody and, if the economic system is able to produce more, how this "social surplus" is distributed.

The "social surplus" is defined by Martins as the "part [of production] which is not necessary for the reproduction of the existing economic system (such as

[59] In Sraffa's terms: "each commodity, which initially was distributed between the industries according to their needs, is found at the end of the year to be entirely concentrated in the hands of its producer. There is a unique set of exchange-values which if adopted by the market restores the original distribution of the products and makes it possible for the process to be repeated" (Sraffa, 1960, § 1).

[60] And then one has to adopt the definition of economics from Robbins (1932): "economics is the study of the allocation of scarce resources which have alternative uses" (cited in Martins, 2013).

luxury goods, or further means of production used in order to expand production beyond the existing economic system)". The social surplus is therefore composed by net investment and luxury goods. But how to define luxury goods? By the help of the capability approach, as for Martins, the means of subsistence are equivalent to the means needed to fulfill the basic capabilities:

> "in order to know which part of production is not necessary for the reproduction of the existing economic system, while allowing for the maintenance of a certain standard of human well-being, we need to know which part of production is necessary for achieving the standard of human well-being we aim at. The capability approach, developed by Sen and Nussbaum, can play a central role here, by defining the level of basic capabilities which are essential for the reproduction of the economy and society under a given, customary, standard of living" (Martins, 2013).

Is the definition of the surplus by Sraffa equivalent to the definition given by Martins? If non-basic goods in Sraffa are equivalent to luxury goods in Martins, then the two definitions are the same. However, it is possible that some non-basic goods are needed for the subsistence of the workers. Actually this is made possible by Sraffa as, in his work, the wage is entirely given "post-factum": thus the wage does not appear as the price of labor, but as a distribution variable and labor is thus not seen as a basic good. If the wage were entirely paid "ante-factum", thus labor would appear as a basic good, and the wage as the price needed for the reproduction of this basic good. In this case, all non-basic goods could safely be considered as luxury goods. Sraffa is well aware of that fact, but nevertheless chooses the first possibility, as a more classic way of representing wage:[61]

> "besides the ever-present element of subsistence, [wages] may include a share of the surplus product. In view of this double character of the wage, it would be appropriate, when we come to consider the division of the surplus between capitalists and workers, to separate the two component parts of the wage and regard only the 'surplus' part as variable; whereas the goods necessary for the subsistence of the workers would continue to appear ... among the means of production. We shall, nevertheless, ... follow the usual practice of treating the whole of the wage as variable. The drawback of this course is that it involves relegating the necessaries of consumption to the limbo of non-basic products. This is due to their no longer appearing among the means of production on the left-hand side of the equations: so that an improvements in the methods of production of necessaries of life will no longer directly

[61] England (1986) adds that choosing the second possibility would mean adding a process of production of labor, with consumption goods as inputs. But this process of consumption is not asking for a rate of profit: this is why it is easier to choose the first option.

> affect the rate of profits and the prices of other products. Necessaries however are essentially basic and if they are prevented from exerting their influence on prices and profits under that label, they must do so in devious ways (e.g. by setting a limit below which the wage cannot fall; a limit which would itself fall with any improvements in the methods of production of necessaries, carrying with it a rise in the rate of profits and a change in the prices of other products)" (Sraffa (1960), § 8).

The idea of Martins is that this limit "below which the wage cannot fall" could be express in terms of basic capabilities. This definition of the customary level of wage would be of course the result of an institutional arrangement between the social actors. What is above this customary level can then be defined as a surplus. This surplus is not needed by the system in order to reproduce itself and to provide basic capabilities: his social value is thus really low, unless it is reinvested into productive activities in order to raise the well-being of all society, or redistributed to the poor people without access to the basic capabilities. This reinvestment and redistribution could be achieve through taxation of the surplus. Taxation of the surplus, as noted by Ricardo and Sraffa, does not change the price of basic commodities and the rate of profit of the standard system. Hence it does not have an impact on the production and the consumption of those goods that are needed by the system in order to reproduce itself. The same happens to taxation on rents. However, there can be a redistribution of the surplus by other means, e.g. "raises in minimum wage, reductions of working hours, or of the retirement age" (Martins, 2013). These are ways to improve the standard level of living without calling for a permanent growth of the economic system.[62]

Permanent growth is actually needed if one is stuck in the neoclassical paradigm. In this paradigm, all goods are scarce since human needs are never satisfied. Thus it is possible to define differential rents for all goods, in a Ricardian way, and to explain prices in terms of an equilibrium between supply and demand. In this paradigm, labor is also scarce: his price depends on the supply and demand for labor. Hence only permanent growth can ensure that wages will grow up (though with the condition that the population level does not grow faster than the economic production). Thus an increase of the standard level of living depends only on growth and taxation would only disrupt the efficient allocation of scarce goods by the market. According to Martins, the whole problem of the neoclassical analysis is therefore its definition of scarcity, which apply to all goods and which is linked with its definition of well-being, i.e. a scarcity which is defined relatively. This vision of a world full of relatively scarce goods is precisely why the neoclassical paradigm is not the good one to analyze absolute scarcity:

[62] Marx offers an other way to increase this standard level of well-being by radically changing the social relations that govern both production and distribution.

> "by trivializing the notion of scarcity, arguing that everything is scarce, rather than focusing on the scarcity of natural resources, mainstream (neoclassical) economists divert our attention away from the study of the natural resources which are actually scarce, rather than contributing to a study of sustainable processes of socio-economic reproduction ... Any attempt to achieve a sustainable world must start by abandoning the (neoclassical) belief that human beings are never satisfied with a limited amount of goods" (Martins, 2013).

Hence the classical approach, interested in the reproduction of the system in order to answer objective basic needs and bypass absolute scarcity, is much more compatible with sustainability analysis. This approach also enables political and ethical considerations to be a part of the definition of those basic needs, and the protection of nature could enter in the discussion as a valuable ethic point of view. In Martins terms:

> "we need a conception where we can define a certain limited standard of human well-being, which enables the reproduction of the economy, society and nature, in a circular process. The capability approach provides a framework within which we can engage in discussions about the standard of living, defined in terms of basic capabilities. And the capability approach is part of an older perspective, which goes back at least to the classical political economists, in which the economy must be seen as a circular process of sustainable reproduction, where the surplus should be used efficiently, in a non-wasteful way" (Martins, 2013).

5.2.9 Conclusion on the second direction

Sraffa (1960) draws his inspiration from the classical economists (Smith, Quesnay, Ricardo, Torrens, Malthus and Marx are cited in appendix D of his book). Martins (2013) and Douai (2009) both think that inspiration from Classical economics can help ecological economics to stand out from neoclassical economics and to define ways for a political economy which could assess the needs of the human society and the possibility to distribute the results of the production in order to fulfill all basic capabilities, rather than pursuing an economic growth which harms the environment. According to Burkett (2006) and Harribey (2013), drivers of this economic growth are to be found in the definition of capitalism. Thus a way to find more sustainable ways of producing is to understand how the capitalist system develops and justifies itself (see also Boltanski and Chiapello, 1999).

The representation of the economy from Sraffa is a capitalist one, in the sense that commodities are owned and exchanged in a market and that workers receive a wage for their labor force. However, the distribution of the surplus could be decided in various ways: e.g. it could be a State decision, with several rate of profits which are only used for investment, in order to meet the future demand for employment and for consumption goods (see Pasinetti, 1988a, 1993); or everything could be given to the workers. In addition to that, the decision to produce or to introduce new techniques are not necessarily the result of profit maximisation decisions: the Sraffian framework is open to all sort of decision process. England (1986) states that, in this decision process, there could be a fight between capitalists, environmentalists and workers. This fight is also represented in Perrings (1987) and O'Connor (1993b). According to them, the result is often that the environment is not considered by the economic valuation process, leading to environmental externalities, free extractions and free exactions from and into the environment.

This vision is contested by Burkett (2004) because for him their is no inherent conflict between workers and environmentalists: both classes should fight the capitalist mode of production. But who are the environmentalists? Martinez-Alier (1995) reveals many ecological conflicts that are linked with distributional problems and shows that actors of these conflicts are variegated. The use of the Sraffian theory could help to investigate the question of the distribution of the economic production, but it cannot help to investigate ecological distribution, and to value environmental destruction. Only a political process can ensure that all kind of values will be accounted into such assessment.

5.3 The third direction: rent and social metabolism

This section presents two kinds of works:

1. Kratena (2008) and Kemp-Benedict (2014) present two ways to introduce the concept of rent into ecological macro-economics;

2. Baumgärtner et al. (2001), Alcántara and Padilla (2009) and Butnar and Llop (2011) do not refer to the economic results of Sraffa's approach, but use his way of presenting the system of production in order to highlight the environmental consequences of industrial production.

5.3.1 Kratena: differential rent

Kratena (2008) produces an Input-Output model in order to calculate the economic impact for human industries of overshooting the Biocapacity. This economic impact is calculated looking at the cost to reduce the Ecological Deficit for each industry. This Deficit is the difference between the Ecological Footprint and the Biocapacity of each industry. The Ecological Footprint (or carrying capacity) is defined as the "biologically productive space that would be necessary to supply all resources a nation's population consumes and to absorb all the wastes that are generated" (Kratena, 2008). The Biocapacity is defined as "the capacity of ecosystems to produce useful biological materials and to absorb waste materials generated by humans, using current management schemes and extraction technologies"[63] and is measured at the national level. Starting from these definitions, Kratena applies Ecological Footprint and Biocapacity concepts at the industrial sectors level and thus defines the Ecological Deficit of each industry.

He then assumes that, in order to eliminate the Ecological Deficit, each industry needs to rent a land area corresponding to this deficit, and needs to cultivate it in order to make it "biophysically productive" (Kratena, 2008). This cost of renting and of cultivating the additional land rises the price of the goods produced by the polluting industry. Furthermore, Kratena assumes that there are decreasing returns to scale in this additional activity (the coefficients of the I-O matrices are not constant, but depends on the level of the output produced). These decreasing returns lead to the apparition of Ricardian differential rents, as industries with positive Ecological Deficit have a lower efficiency in production (measured as the quantity of input per unit of output produced) than industries without this Ecological Deficit. The price of commodities in his model is composed of three parts, the cost of producing under the Biocapacity level, the cost of cultivating the additional land if there is overshooting and the Ricardian rent if some industries have an higher overshooting:

$$\mathbf{p} = \bar{\mathbf{v}} \left[\mathbf{I} - \hat{\mathbf{E}}\right] \left[\mathbf{I} - \mathbf{A}\right]^{-1} + \mathbf{v}^{*}\hat{\mathbf{E}} \left[\mathbf{I} - \mathbf{A}^{*}\right]^{-1} + \rho \tag{5.74}$$

[63] This definition is from: www.http://www.footprintnetwork.org

With $\mathbf{p}$ the price vector, $\bar{\mathbf{v}}$ the value added vector for the part of the output in line with Biocapacity (the value added coefficients comprise "labor inputs and different capital input components (depreciation, gross operating surplus) per unit of output"[64] Kratena, 2008), $\hat{\mathbf{E}}$ the diagonal matrix of the coefficients representing the part of output corresponding to overshooting), $\mathbf{A}$ the matrix of technical coefficient, $\mathbf{v}^*$ the value-added vector for the part of output needed to reduce the overshooting, $\mathbf{A}^*$ the matrix of technical coefficients with decreasing returns to scale, and ρ the differential rent. Multiplying the differential rent of all sectors with the vector of quantities produced, Kratena is then able to calculate the "Total Ricardian Rent" for the national economy.

According to Kratena, to introduce this decreasing returns to scale is important as it expresses the fact that the environment is a binding constraint to the economic activity. Hence he claims two things: first that, as this additional activity produces natural capital (biophysical production), he is following the "strong sustainability" paradigm. However, this is wrong: he is not claiming that the natural capital should be substituted by "man-made" capital, but if the natural capital is now been produced by an economic activity, it becomes in effect a intermediary product, i.e. natural capital becomes "man-made" capital. Kratena is thus claiming for a weak sustainability vision, as the environmental overshooting can be reduced to an economic activity. The fact that this activity shows decreasing returns does not help, as it is still a replacement of natural processes by economic processes.

Second Kratena says that, when there is a binding constraint, the non-substitution theorem (Samuelson, 1966) does not hold. But actually this theorem says that with constant coefficients, single production and no exogenous resources except one (e.g. labor), one technique minimizes all prices when the wage is given, and a change in output (or demand) will not change prices. However, Kratena models works with non constant coefficients, as he is assuming decreasing returns to scale in the additional activity needed to reduce the Ecological Deficit. Furthermore Pasinetti (1977) already showed that substitution in neoclassical theory means an inverse relation between proportion of two inputs and their relative prices and that such substitution is a phenomenon which is not verified in Sraffa's type model of production (and thus also in Leontief type model of production): "in a production context with a given technology - with or without joint products - the traditional concept of substitution makes no sense" (Pasinetti, 1977). Arguing that the non-substitution theorem in Kratena's model does not hold is therefore wrong: with a change of output, prices will change, but this is not due to a phenomenon of substitution.

5.3.2 Kemp-Benedict: absolute rent

Kemp-Benedict (2014) writes an interesting article about the vertically inte-

[64] This is main difference between the approach of Leontief (1970), which is followed by Kratena, and the approach of Sraffa: in Leontief, the value added coefficient are expressed in money terms, i.e. their prices is known, whereas in Sraffa only quantities are expressed, e.g. quantities of labor (and the wage is not known).

grated structure of the economy. The goal of this representation is to highlight aggregated markups, which apply on one hand to labor and on the other hand to the rent from the exploitation of natural resources.

These aggregated markups are constructed from a three sector economic model with sector 3 extracting natural resources, sector 2 transforming these raw materials into bulk commodities, and sector 1 producing intermediate commodities (used in all sectors) from bulk commodities. The final demand consists of intermediate commodities.

Matrix $\mathbf{A}$ of input coefficients, vector $\mathbf{l}$ of labor coefficients and matrix $\mathbf{B}$ of output coefficients are then represented in this way (here processes are in column, and commodities in line):

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & 0 & 0 \\ 0 & a_{32} & 0 \end{pmatrix} \tag{5.75}$$

$$\mathbf{l} = \begin{pmatrix} l_1 & l_2 & l_3 \end{pmatrix} \tag{5.76}$$

$$\mathbf{B} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{5.77}$$

The system of equation for the physical side is:

$$\mathbf{By} = \mathbf{Ay} + \mathbf{d} \tag{5.78}$$

With $\mathbf{y}$ the activity vector and $\mathbf{d}$ the final demand vector.

The system of equation for the value side is:

$$\mathbf{pB} = (\mathbf{pA} + w\mathbf{l} + \mathbf{r})\,\mathbf{\Pi} \tag{5.79}$$

With $\mathbf{p}$ the price vector, $\mathbf{\Pi}$ the diagonal matrix of markups (equivalent to sector-specific rates of profit), w the wage (uniform in all sectors) and $\mathbf{r}$ the vector of rents. Kemp-Benedict assumes that each sector performs mark-up pricing so that they each have a different rate of profit:

$$\Pi = \begin{pmatrix} 1+\pi_1 & 0 & 0 \\ 0 & 1+\pi_2 & 0 \\ 0 & 0 & 1+\pi_3 \end{pmatrix} \tag{5.80}$$

Furthermore the vector of rents only have one component different from zero, the rent of sector 3:

$$\mathbf{r} = \begin{pmatrix} 0 & 0 & r \end{pmatrix} \tag{5.81}$$

Knowing the final demand, it is possible to know the level of production in each sector, and the level of employment L:

$$\mathbf{y} = [\mathbf{B} - \mathbf{A}]^{-1}\,\mathbf{d} \tag{5.82}$$

$$L = \mathbf{ly} \tag{5.83}$$

Knowing the wage (uniform in all sectors), the rents on natural resources and the markups in each sector, it is possible to deduce the prices:

$$\mathbf{p} = (w\mathbf{l} + \mathbf{r})\,\Pi\,[\mathbf{B} - \mathbf{A}\Pi]^{-1} \tag{5.84}$$

Multiplying final demand with the price vector, it is then possible to calculate the GDP of the economy. Indeed, we have:

$$GDP = \mathbf{pd} = (w\mathbf{l} + \mathbf{r})\,\Pi\,[\mathbf{B} - \mathbf{A}\Pi]^{-1}\,[\mathbf{B} - \mathbf{A}]\,\mathbf{y} \tag{5.85}$$

And Kemp-Benedict demonstrates that it is possible to represent GDP as :

$$GDP = X_w wL + X_r r y_3 \tag{5.86}$$

With X_w the aggregated markup on wages and X_r the aggregated markup on rents, both depending only on technology and markups (independent from prices and levels of activity).[65]

From this last representation of GDP, Kemp-Benedict deduces some observations about taxation of rents, natural resource productivity and resource return on investment (RROI, "given by the ratio of the amount of raw material extracted, divided by the direct and indirect use of that raw material in its extraction" Kemp-Benedict, 2014). One interesting point is that if RROI becomes too low, then, at one point, the markups on wage and rents become infinite and the economy cannot run anymore. He also found that the aggregated markup on rents is higher than the aggregated markup on wages: $X_r > X_w$ and that the economy-wide mark-ups are larger than sector-specific mark-ups.

As regards theory of value, Kemp-Benedict approach is a bit unclear. The interesting aspect of his approach is to take into account absolute rent, which is not represented in Sraffa's system. Kemp-Benedict explains that rents are the price of the exploitation permits. Rent appears in the system of equation as the third distribution variable, along with wage and profit. This representation is possible and expresses the result of an institutional arrangement between rentiers, capitalists and workers. But his theory of price is less convincing. He first explains that prices are the result of mark-up pricing (firms chose the rate of profit each wants to earn, and they sell their product at a price equivalent to the cost of production plus their mark-up), but with the exception of firms that produce raw materials, as their prices are "determined by their availability relative to their demand, in marginalist fashion" (Kemp-Benedict, 2014). He justifies this because there is no possible substitution of raw materials in the short term, but in his model, Kemp-Benedict finally chooses to use only markups pricing. He then explains that it is possible to have different markups for different sectors, but latter he find more convenient to assume a uniform rate of profit.

[65] Details about the calculation of these markups are given in Kemp-Benedict (2014).

Actually from a Sraffian point of view, in the system of equation described by Kemp-Benedict, all goods are basic and all processes are interdependent. Hence only a uniform rate of profit is possible, once the wage and the rents are given. It is thus not easy to understand what findings in terms of political economy we could learn looking at aggregated markups. Kemp-Benedict attempts to express the part of GDP which is based on the use of environmental resource, as he tries to reveal Daly's "inverted pyramid" (natural resources extraction account for only 5% of the global GDP but actually all production is related to this initial extraction, Daly, 1995). However, I think he is not revealing the part of GDP related to the extraction of natural resources by doing this, because if there would not be any extraction, then the GDP would be equal to zero. Extracting natural resources is a necessary condition, in his system, to produce economic values. What he is actually revealing with equation 5.86 is therefore by how much the value of the GDP has increased when a rent on natural resources is added.

If there were no rents, the GDP value would be equal to:

$$GDP = X_w w L \tag{5.87}$$

Hence by adding the rent, the GDP increases. But this does not mean that production has increased, and that aggregated mark-up X_r in equation 5.86 shows the part of production which is created by the environment. GDP has increased, but just because now someone expects a return on natural resources extraction. Kemp-Benedict does not acknowledge that, and even think that if the labor is made endogenous, we could have a better accounting of the part of the GDP coming from the environment, referring to the energy theory of value developed by Costanza (1980).

Nevertheless, his approach is interesting because he tries to express absolute rents and because he develops some physical indicators of the efficiency of the system, through a vertical integration analysis.

5.3.3 Joint Production

All production of goods also produces bads: the economic notion which expresses this relation is joint production. This phenomenon is clearly revealed when one looks at production from the point of view of thermodynamics. In the general case, we have the production of low entropy goods from high entropy raw materials, using low entropy energy; but there is always joint production of high entropy wastes. Indeed, the Second Law of Thermodynamics states that all transformations create a positive quantity of entropy: this implies that all transformation are irreversible. And it also implies that there is a limit to the substitution of inputs inside the processes of production: we must at least have a raw material with low entropy, usually energy, if we want to create low entropy goods. At last this entails that there will always be some waste to handle, and that a zero-waste society is an utopia. If all three implications are aggregated, questions about the limits to economic growth can arise (Meadows et al., 1972).

Baumgärtner et al. (2001) question the relevance of the joint production concept for the ecological economics field, which looks to get away from the neoclassical paradigm. In the history of economic thought, mainly two scenarios have been considered: the case where all joint products are goods, and the case where at least one joint product is a waste and one is a good. The second scenario seems to relate directly with the concerns of ecological economics. Applications in the case of optimization of industrial production systems (for instance complex bio-refineries process of production, Centi et al., 2011; Sharma et al., 2011; Tay et al., 2011) can be found. Other applications lies in the understandings of the relation on a more global scale between the economy and its environment (e.g. see Perrings, 1987 and O'Connor, 1993a for a study of the possibility for an ever-growing economy to subsist if the environment has only a limited capacity to produce low entropy resources and to absorb high entropy wastes).

Joint production also raises question on a philosophical level: what about the ethics of producers of waste that are not (yet) taken into account by society? Should the company producing the waste be proactive about the question of waste management, or should the company wait that society acknowledges the brute fact of joint production and decides something? This raises the question of risk management and of precautionary principle, in an epistemological way.

The concept of joint production is a simple one, easily understood by anybody: it is thus a good concept for knowledge mediation in order to raise awareness on environmental concerns. This is a universal concept, which could be applied on different spatial scales – scale of a company, regions, world, etc. – or time scales – as the time scales of goods (production and consumption) and bads (recycling and absorption by the environment) are usually not the same. This is a systemic approach, which encourages to consider at the same time resources and wastes: "the resource is the mother of the waste" (Baumgärtner et al., 2001). Joint production concept also allows to go over the classical link between negative externalities and compensation for damages or restoration, by showing the link between goods production and negative externalities – and thus it allows us to reconsider production before having to repair the mistakes. To summarise, this concept describes the links between natural systems and human activity, describes human economy, highlights the responsibilities and the limits of human knowledge, and furthermore appears as a clear and easy-to-understand concept (in opposition to the concept of entropy, for instance).

In my point of view, this concept is a good one to highlight the inherent link between production of commodities and services and production of waste. However, in an other article, Baumgärtner et al. (2002) deals with the possibility to link capital theory with this view of joint production. Joint production is, indeed, a concept which originates from thermodynamics laws and thus should be appropriated (or at least understood) by all theories of value. Baumgärtner tries to look if it can fit within the neoclassical theory of capital (Hotelling, 1931; Barro and Sala-i Martin, 1995). I attempt to point that this approach of capital cannot fit within the Sraffian framework in section 7.4.

5.3.4 Subsystem analysis

A subsystem is defined by Sraffa in Appendix A of his book (Sraffa, 1960):

> "a system can be subdivided into as many parts as there are commodities in its net product, in such a way that each part forms a smaller self-replacing system the net product of which consists of only one kind of commodity. These parts we shall call 'sub-systems"'.

A subsystem represents then all the quantities needed to produce, directly and indirectly, one specific commodity or a group of several specific commodities. The construction and the analysis of these subsystems have been investigated by Pasinetti (1973; 1988a) in order to understand the dynamics of a system of production. Alcántara and Padilla (2009) uses this concept to investigate the induced emission of CO_2 of all sectors of an economy due to the production of one specific consumption good: they take as an example the service sector in Spain.

Their model starts from the usual physical relations in single production:

$$\mathbf{Aq} + \mathbf{c} = \mathbf{q} \tag{5.88}$$

With $\mathbf{A}$ the matrix of technical coefficients, $\mathbf{q}$ the vector of quantities produced, $\mathbf{c}$ the vector of consumption goods and services produced. Knowing the consumption of the period, the produced quantities are:

$$[\mathbf{I} - \mathbf{A}]^{-1} \mathbf{c} = \mathbf{q} \tag{5.89}$$

Now equation 5.88 can be rewritten in this way:

$$\mathbf{A} [\mathbf{I} - \mathbf{A}]^{-1} \mathbf{c} + \mathbf{c} = \mathbf{q} \tag{5.90}$$

The produced quantities are decomposed into final consumption and intermediary consumption. Each line of the Leontief matrix $[\mathbf{I} - \mathbf{A}]^{-1}$ expresses the intermediary quantities needed to produce one unit of the related final consumption good: for the sake of simplicity this matrix will be now denoted as matrix $\mathbf{L} = [\mathbf{I} - \mathbf{A}]^{-1}$. In order to have the quantities produced by a subsystem, it is then sufficient to set all the coefficients but one of the final consumption vector to zero:

$$\mathbf{ALc}^i + \mathbf{c}^i = \mathbf{q} \tag{5.91}$$

With $\mathbf{c}^i$ the consumption vector with all components but coefficient i equal to zero. Alcantara and Padilla then goes a bit further by decomposing matrix $\mathbf{A}$ into a diagonal matrix plus a matrix with only zeros on the main diagonal:

$$\left[\mathbf{A}^D + \mathbf{A}^0\right] \mathbf{Lc}^i + \mathbf{c}^i = \mathbf{q} \tag{5.92}$$

This system can be further decomposed by separating the lines corresponding to the processes of production of the sector i (if there are several industries in the sector, there will be several lines in that sector) from the other sectors of production (the m other industries):

$$\left[\begin{pmatrix} \mathbf{A}^D_{mm} & 0 \\ 0 & \mathbf{A}^D_{ii} \end{pmatrix} + \begin{pmatrix} \mathbf{A}^0_{mm} & \mathbf{A}^0_{mi} \\ \mathbf{A}^0_{im} & \mathbf{A}^0_{ii} \end{pmatrix}\right] \begin{bmatrix} \mathbf{L}_{mm} & \mathbf{L}_{mi} \\ \mathbf{L}_{im} & \mathbf{L}_{ii} \end{bmatrix} \begin{bmatrix} 0 \\ \mathbf{c}^i \end{bmatrix} + \begin{bmatrix} 0 \\ \mathbf{c}^i \end{bmatrix} = \begin{bmatrix} \mathbf{q}^m_i \\ \mathbf{q}^i_i \end{bmatrix} \tag{5.93}$$

This allows to decompose the impact in terms of produced quantities of the consumption of the good i into five components:

1. The "demand volume component", represented by the term $\mathbf{c}^i$, i.e. the production of the consumption good i.

2. The "spill over component", represented by the term $\mathbf{q}^m_i = \mathbf{A}^D_{mm}\mathbf{L}_{mi}\mathbf{c}^i + \mathbf{A}^0_{mm}\mathbf{L}_{mi}\mathbf{c}^i + \mathbf{A}^0_{mi}\mathbf{L}_{ii}\mathbf{c}^i$, i.e. the quantities that are produced in the other m sectors in order to enable the production of consumption goods of sector i.

3. The "feed-back component", represented by the term $\mathbf{A}^0_{im}\mathbf{L}_{mi}\mathbf{c}^i$, i.e. the quantities of the good i which serve as intermediary consumption in the m other sectors in order to enable the production of the consumption goods of sector i.

4. The "own component", represented by the term $\mathbf{A}^D_{ii}\mathbf{L}_{ii}\mathbf{c}^i$, i.e. the quantities of the own good they produce that are needed by each industry of sector i as an intermediary consumption in order to enable the production of the consumption goods of sector i.

5. The "*intra* spill over component", represented by the term $\mathbf{A}^0_{ii}\mathbf{L}_{ii}\mathbf{c}^i$, i.e. the quantities of the goods produced by the other industries of sector i that are needed by each industry of sector i as an intermediary consumption in order to enable the production of the consumption goods of sector i.

By adding a vector $\mathbf{e}$ representing CO_2 emissions per unit of output in each industry, it is then possible to know the emissions due to the production of consumption goods in subsystem i, and then to decompose such emissions for all five components. It is furthermore possible to know the emissions of the sector i due to the production of consumption goods in the other m industries, by rewriting system 5.93 as:

$$\begin{bmatrix} \mathbf{A}_{mm} & \mathbf{A}_{mi} \\ \mathbf{A}_{im} & \mathbf{A}_{ii} \end{bmatrix} \begin{bmatrix} \mathbf{L}_{mm} & \mathbf{L}_{mi} \\ \mathbf{L}_{im} & \mathbf{L}_{ii} \end{bmatrix} \begin{bmatrix} \mathbf{c}^m \\ 0 \end{bmatrix} + \begin{bmatrix} \mathbf{c}^m \\ 0 \end{bmatrix} = \begin{bmatrix} \mathbf{q}^m_m \\ \mathbf{q}^i_m \end{bmatrix} \tag{5.94}$$

These emissions are then calculated by multiplying vector $\mathbf{e}$ with the component $\mathbf{q}^i_m = \mathbf{A}_{im}\mathbf{L}_{mm}\mathbf{c}^m + \mathbf{A}_{ii}\mathbf{L}_{im}\mathbf{c}^m$.

This analysis of emissions per subsystem is deepened by Butnar and Llop (2011), who study the determinants of changes of CO_2 emissions on the subsystem level, through structural decomposition. In order to do this, they define a subsystem of production in the same way as Alcántara and Padilla (2009), but they only decompose it into three components and then multiply each component by their emissions vector ($\mathbf{e}^i$ for the emissions per unit of output of the subsystem industries, $\mathbf{e}^m$ for the emissions of the other industries). The three components are:

1. The "demand level component", $DLC = \mathbf{e}^i\mathbf{c}^i$, equivalent to the "demand volume component" of Alcantara and Padilla;
2. The "external component", $EC = \mathbf{e}^m\left(\mathbf{A}_{mm}\mathbf{L}_{mi} + \mathbf{A}_{mi}\mathbf{L}_{ii}\right)\mathbf{c}^i$, equivalent to the "spill over component" of Alcantara and Padilla;
3. The "internal component", $IC = \mathbf{e}^i\left(\mathbf{A}_{im}\mathbf{L}_{mi} + \mathbf{A}_{ii}\mathbf{L}_{ii}\right)\mathbf{c}^i$, equivalent to the addition of the "feed-back", the "own" and the "intra spill over component" of Alcantara and Padilla;

The total emission due to the production of consumption goods in subsystem i is thus written as follows:

$$E = DLC + EC + IC \tag{5.95}$$

The starting point of the structural decomposition is to assume that changes in total emission E is due to changes, at different levels, in the three components:

$$\Delta E = \Delta DLC + \Delta EC + \Delta IC \tag{5.96}$$

The changes of emissions in each component can then be the result of a change in the emission coefficients (change in the "emission term", ET) or the result of a change in the technical coefficients ("technological term", TT) or finally the result of change in final demand ("demand term", DT). All three determinants can of course change at the same time, but the goal of structural decomposition is precisely to understand how each determinant impacts the total emission change. The difficult task with structural decomposition is to understand how determinants are related to each other:[66] for instance, for the demand level component, Butnar and Llop assumes that changes in emission coefficients are independent from changes in final demand. However, in the external and the internal components, the changes of emissions are considered to be dependent with the changes of technical coefficients, so that the technological term includes both, whereas changes in demand are assumed to be

[66] And it is possible to find a residual which is not explained by the chosen independent determinants: here Butnar and Llop chose to allocate this residual to each determinant (following the method proposed by Bennet, 1920).

independent from changes in technology. The structural decomposition of total emission is then:

$$\Delta E = \Delta ET_{DLC} + \Delta DT_{DLC} + \Delta TT_{EC} + \Delta DT_{EC} + \Delta TT_{IC} + \Delta DT_{IC} \quad (5.97)$$

If the assumptions are correct, it is therefore possible to better understand the reasons for a change of the emissions of one subsystem, and thus to better identify which policy will help to reduce those emissions.

Chapter 6

Promising paths

6.1 Introduction

I think the Sraffa's approach can be interesting for ecological economics because it offers a constructive alternative to the neoclassical methodology and because it could help to support some views in the heated debates of the ecological economics field. I will deal in this chapter with some constructive aspects that can be built from Sraffa's methodology, on natural resource economics (renewable and non-renewable) and the question of wastes and pollution, in section 6.2. I will then attempt to show how the Sraffian approach could be used to shed a new light on the debate around the value of nature (and around the notion and the payment for ecosystem services) and the possibility to build a circular economy in section 6.3.

6.2 Representing the real economy

Let us start with a simple system of production with three processes: here I use the same system as in Kemp-Benedict (2014). Process 1 produces raw material from a given natural resource , process 2 produces bulk commodities from raw material and process 3 produces a capital good which is used by all processes. The input-output representation could be written, with **A** the inputs matrix, **B** the output matrix (processes are in rows, goods are in columns) and **l** the column vector of the shares of total labor used by each process:

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & a_{13} \\ a_{21} & 0 & a_{23} \\ 0 & a_{32} & a_{33} \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ 0 & 0 & b_{33} \end{bmatrix}; \mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \end{bmatrix} \tag{6.1}$$

With $l_1 + l_2 + l_3 = 1$. The price system can be written in this way:

$$(1+\pi)\,\mathbf{Ap} + w\mathbf{l} = \mathbf{Bp} \tag{6.2}$$

With $\mathbf{p}$ the column vector of prices, π the rate of profit and w the wage.

6.2.1 Price system and the influence of distribution

In order to calculate static Sraffian prices, we have to find the standard system, by multiplying all processes by adequate coefficients in order to have the same ratio between surplus and inputs for each commodity, while keeping the sum of labor coefficients equal to one. Here a numerical example of the standard system could be:

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} 2 & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 6 \end{bmatrix}; \mathbf{l} = \begin{bmatrix} \frac{1}{3} \\ \frac{1}{3} \\ \frac{1}{3} \end{bmatrix} \tag{6.3}$$

The maximal rate of profit is thus (when the wage is equal to zero):

$$R = \frac{p_1 + p_2 + 3p_3}{p_1 + p_2 + 3p_3} = 1 \tag{6.4}$$

If the standard commodity is chosen as the numeraire (i.e. if $p_1 + p_2 + 3p_3 = 1$), the relation between the rate of profit π and the wage w becomes:

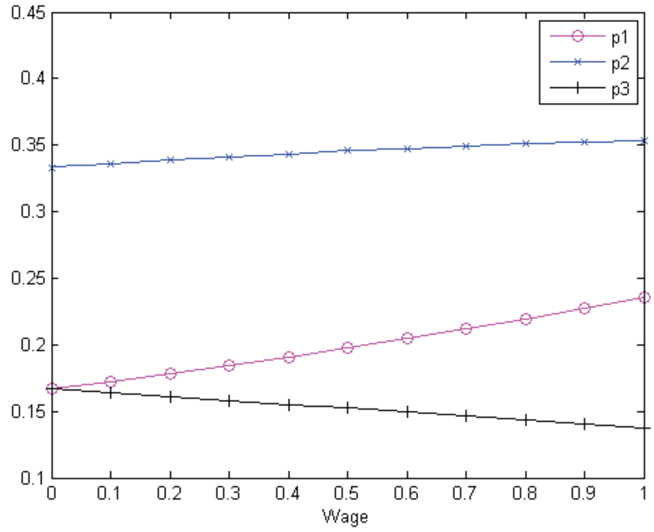
$$\pi = 1 - w \tag{6.5}$$

With $0 \leq w \leq 1$. The relation between the distribution variables influence the prices. If wage is given, the price solution is:

$$\mathbf{p} = \left[\mathbf{B} - (2-w)\,\mathbf{A}\right]^{-1} w\mathbf{l} \tag{6.6}$$

We can see the evolution of prices depending on the distribution of the surplus in Fig. 6.1:

Figure 6.1: Evolution of prices depending on distribution



6.2.2 Natural resources

6.2.2.1 How to represent natural resources?

The natural resource is not represented in Sraffa's price system, but nevertheless supports the production process (otherwise no raw material could be produced). One way to reveal its importance is to look at the physical consequences of the depletion of this stock. The general law, in this case, is that the more a resource becomes scarce, the more difficult is its extraction (this concerns all extractive industries, but also forestry, fishery, etc.). A realistic function of extraction should be in the form:[1]

$$b_{11}(t) = \alpha S(t) \tag{6.7}$$

With $S(t)$ the physical stock of natural resource, and α a positive coefficient. That is, the extraction cost is positively related with the stock of natural resource left in the ground.

Now, because the raw material produced from the extraction of the natural resource is a basic commodity, as soon as its method of production changes, the standard system will also change. It means that the standard of value used in the initial situation will change, so the comparison between prices after

[1]This idea comes from the economics of renewable resources (Gordon, 1954; Schaeffer, 1954), following a presentation from Erreygers (2014) on the application of this subject to neo-Ricardian economics.

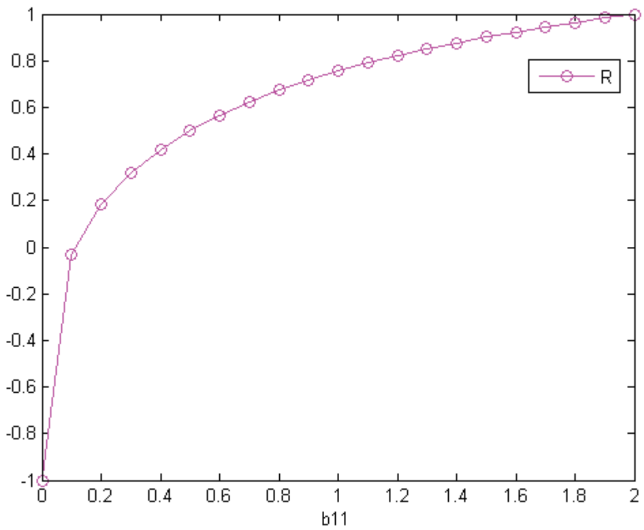
and before this change is meaningless.[2] Hence comparisons between different periods of production should be done on the physical level, not on the value level. Is the physical rate of surplus (equal to the maximum rate of profit) changed? Is the productivity of one hour of labor different? These are physical variables that can be compared among different periods of production.

If we go back to the numerical case of subsection 6.2.1, we could arrive to the case where the extraction of raw material is more difficult:

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11}(t) & 0 & 0 \\ 0 & 2 & 0 \\ 0 & 0 & 6 \end{bmatrix}; \mathbf{l} = \begin{bmatrix} \frac{1}{3} \\ \frac{1}{3} \\ \frac{1}{3} \end{bmatrix} \tag{6.8}$$

With $0 \leq b_{11}(t) \leq 2$. In this case, we can look at the evolution of the maximal rate of profit depending on the production of raw material in Fig. 6.2:

Figure 6.2: Evolution of maximal rate of profit depending on extraction of raw material



We must note that the exchange value system is different from the physical exchange system. In this case physical exchanges can be represented in this way (with the inclusion of natural resource, commodity 4,):

[2]If the raw material is a non-basic commodity, the price of this material will change, but the other prices will not be affected, and thus a comparison between values is possible.

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & a_{13} & a_{14} \\ a_{21} & 0 & a_{23} & 0 \\ 0 & a_{32} & a_{33} & 0 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \end{bmatrix}; \mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ l_4 \end{bmatrix} \quad (6.9)$$

We see here the problem that, when we start with the description of physical exchanges, we cannot get the same set of prices as in the situation where we already know the value exchanges (i.e. the exchanges of commodities and services which bear a price). Looking at system 6.14, how to construct a standard system? The natural resource must be eliminated, and this can only be done by deleting process 1. We are left with process 2 and 3, but process 2 uses commodity 1, which is not produced anymore because process 1 has been deleted. Thus we must also suppress this process, and we are left with process 3. But because commodity 2 is not produced anymore, we must also delete process 3 and no standard system could arise.

In order to avoid such problems, we must insist on the condition for a resource to get a value in the Sraffian system (we have already presented them in subsection 3.3.3):

Proposition 1. *A resource or a service must be produced in order to get a price, i.e. at least one input must be consumed in order to get the commodity.*

The natural resource cannot then receive a price, as it is not produced.

6.2.2.2 An attempt to represent the natural process of production

The solution devised by O'Connor (1993b) is to represent the process producing the natural resource, i.e. to include in the technology some ecological processes. This would mean that natural processes are equivalent to capitalist processes, selling their product on the market at the end of the production process, i.e. it means that nature has been capitalized. The system would thus become:

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & a_{13} & a_{15} \\ a_{21} & 0 & a_{23} & 0 \\ 0 & a_{32} & a_{33} & 0 \\ 0 & 0 & 0 & a_{55} \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{55} \end{bmatrix}; \mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ 0 \end{bmatrix} \quad (6.10)$$

Process 5 produces the natural resource, with the natural resource as the sole input. The economic system then appears to be a set of three non-basic processes, and the natural process is the sole basic process of the system. If the natural process is not producing a surplus (i.e. if $b_{55} - a_{55} < 0$), it is not possible to produce a set of prices which allows the reproduction of the system. If the natural process is producing just enough to sustain itself (i.e. if $b_{55} - a_{55} = 0$), the price of the natural resource can be calculated first, and then the price of the other resources. A numerical example could be:

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} 2 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 6 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \mathbf{l} = \begin{bmatrix} \frac{1}{3} \\ \frac{1}{3} \\ \frac{1}{3} \\ 0 \end{bmatrix} \tag{6.11}$$

Let us say that the price of the natural resource is the numeraire: $p_5 = 1$. The system of prices then becomes:

$$\begin{array}{c} 1 + \pi = 1 \\ p_3 (1 + \pi) + \frac{w}{3} + 1 = 2p_1 \\ (p_1 + p_3)(1 + \pi) + \frac{w}{3} = 2p_2 \\ (p_2 + p_3)(1 + \pi) + \frac{w}{3} = 6p_3 \end{array} \tag{6.12}$$

If the rate of profit is uniform, it must equal zero. If it is not uniform, it must be noted that the price of the natural resource will remain constant, independently of the distribution of the surplus (and independently of the level of the physical stock of the natural resource). We can also see that, even if the surplus is entirely distributed to the wages, the value of the commodities will not be proportional with the labor needed for their production; then the labor theory of value cannot hold anymore.

If the natural process is producing a surplus (i.e. if $b_{55} - a_{55} > 0$), then a rate of profit could appear on the natural process. If the whole surplus (composed of economic and natural resources) is given to the owner of the natural resource, we are back to a "natural resource theory of value". But on the contrary, if the whole surplus is given to labor, the value of the commodities will not be proportional with the labor needed for their production.

In my point of view, the reason why authors such as O'Connor (1993b) want to introduce natural processes into the system of production is because natural resources must also be reproduced, and thus a price on a natural resource could express its cost of reproduction (here, the cost of reproduction is $p_5 = 1$ when there is no surplus). However, it would only be a cost for the human economy if a real interdependence were existing between natural and human processes. Here, we see that the human economy needs the environment, whereas the reverse is not true; then the human economy would be represented as a set of non-basic processes. The human economy is not reproducing nature, thus the reproduction of nature cannot be a cost for the human economy.[3]

But then why, in a Sraffian system, do non-basic processes buy basic goods? Because they are using a part of the surplus, which is demanded by the capitalists and the workers as a revenue, in exchange for their advance of capital (the capitalists must buy the inputs) and their labor. Who is claiming the surplus

[3]One may wonder if this vision is also true on the global level: planet Earth could be seen as one self-sufficient system of production. In this case the human economy would produce the environment, just as the environment is producing the human economy: all processes would become interdependent. But then no surplus would be available for the distribution of profits. In my point of view this representation is not a fair representation of the way the human economy is functioning.

of nature? It may be that the natural process is capitalized, and that someone makes the surplus his own (or, not only the surplus, but even the whole stock). A price could then be asked: but the owner would not have given anything (capital or labor) in exchange for this revenue. I then claim that the price on the natural resource is equivalent to an absolute rent on the natural resource (see subsection 6.2.4);

Hence we have seen that with this representation, nature is capitalized and the labor theory of value cannot hold anymore. My point of view is that this representation gives credit to the position that exchange value can be created without human labor, just by the fact that someone owns a commodity. It thus offers a justification for a theory of value where there is value as soon as there are exchanges of owned commodities. I do not think that this view, which is radically alien to Classical positions, would have been supported by Sraffa. Furthermore I claim that the current trend for the capitalization of the environment can be analyzed without the need to introduce natural processes into the Sraffian framework. This is why I would replace Proposition 1 with the more Classical oriented proposal:

Proposition 2. *A resource or a service must be produced in order to get a price, i.e. at least labor must be consumed in order to get the commodity.*

6.2.2.3 Management of natural resources

There exists a vast literature in environmental economics about the management of natural resources (Faucheux and Noël 1995; van den Bergh 2002). The literature on non-renewable resources tried to explain that owners of non-renewable resources should receive a rent in order to keep the resource on the ground (Hotelling rent, Hotelling, 1931). As we have seen that this rent cannot arise in a Sraffian framework (section 4.3), the distinction between the management of renewable and non renewable natural resources should be avoided. In each case, the conditions of extraction of the natural resource to produce a raw material depends on the existing stock of natural resource, and the size of this stock may depend from previous extraction. Hence a non-renewable resource can be said renewable if no extraction occurs, and a renewable one can be depleted if the extraction rate is too high.

What should be a Sraffian environmental policy about natural resources? What we have learned is that natural resources have no price. The social impact of their depletion cannot therefore be reflected in their prices, and thus will only be a matter of political and social deliberation. If a natural resource starts to be depleted, its cost of extraction will rise. Hence, either the prices of the raw material will rise (if it is a non-basic good), or the maximal rate of profit will fall (if it is a basic good, as we can see in Fig. 6.2). This could lead ultimately lead to a decrease of the level of production, and thus an increase of the level of unemployment.

An environmental policy should then focus either on the sustainable use of the natural resource, or on the development of substitution techniques, i.e.

techniques that will be more efficient in the use of the natural resource. As regards the first case, the protection of these resources in the case of over-exploitation lies in the regulation between actors. If an individual owns a natural resource, its maximal sustainable rate of extraction can be calculated, if the laws governing the evolution of the stock is known. If several agents use the same natural resource, the constraint of a maximum rate of extraction remains the same but the institutional arrangement between actors may be diverse (free competition, common good regulation, state regulation, etc.).

The question of the best regulation is not easy to answer. Free competition may not ensure the most efficient use of the resource, as no auctioneer exists to centralize all preferences and conditions of production. On the other hand the State may impose an extraction quotas, or an extraction tax, so that the resource will be less used, if he thinks that the depletion of the resource will be negative for the society. As the social impact of the loss of the resource cannot be measured in economic terms, the impact of the extinction of the resource may be measured in terms of loss of employment, and the technical change required in order to keep the same level of production could be assessed.

An environmental policy could then also focus on the development of substitution techniques. This techniques may not arise on their own: the neo-classical mechanism of substitution is not relevant here. This mechanism state that there is "an inverse monotonic relation between the proportions of any two inputs and their relative prices" (Pasinetti, 1977): if the price of an input rises, its use in production should decrease. However, in Sraffian models, the price may not rise depending on scarcity: it is only if the raw material is a non-basic good that this will happen. If the raw material is a basic good, the standard system will change if its process of production changes; and we know that no comparison based on prices can be made between to systems with different standard systems (Sraffa, 1960, § 93).[4] Furthermore, even if the price is rising, substitution may not occur, as we are not looking at general equilibrium systems, but at production systems: "changes in the input proportions and changes in their prices are entirely unrelated" (Pasinetti, 1977). Hence free market policies, which believe that, if there is free competition, the scarcity of the good will be reflected on its price and a substitution between techniques of production will then occur, are based on false premises. They should be avoided in general, and a close investigation on each case (about the consequences of a loss of the resource, and about the development of substitution techniques) should be preferred.

[4]It should be stressed that even in general equilibrium models, the relation between prices and scarcity does not hold. This is a corollary result of the Sonnenschein-Mantel-Debreu theorem (Sonnenschein, 1973; Mantel, 1974; Debreu, 1974, see also Guerrien, 1992).

6.2.3 Waste

6.2.3.1 Costly disposal

What happened if the process 3 also produces a waste whose disposal is costly? Two possibilities then arise: either the industry which produces the waste is able to dispose it of, or it asks for a waste-disposal company to do it. The first case implies that the cost of production will increase in this industry and the second case means that a fourth process, representing the waste-disposal industry, can be introduced. This process will sell the disposal service to process 3 (and will use as inputs some quantity of commodity 3). Thus the input-output representation could become:

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & a_{13} & 0 \\ a_{21} & 0 & a_{23} & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & 0 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix}; \mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ l_4 \end{bmatrix} \tag{6.13}$$

Again it should be noted that commodity 4 is the service of waste disposal: thus the Sraffian representation does not show the physical waste production and exchanges, but only the commodity and services needed to dispose of the waste. A positive price can then be calculated on commodity 4. As the standard system is changed (commodity 4 is basic), a new set of prices will appear, that cannot be compared with the previous ones. But then, we can introduce dynamics by adding the fact that the disposal becomes be more and more costly (for instance because landfill is progressively more taxed), and comparisons based on the evolution of the maximal rate of profit can be done.

We must again note that the exchange value system is different from the physical exchange system. In this case physical exchanges can be represented in this way (with the inclusion of natural resource, commodity 5, and waste, commodity 6):

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & a_{13} & 0 & a_{15} & 0 \\ a_{21} & 0 & a_{23} & 0 & 0 & 0 \\ 0 & a_{32} & a_{33} & 0 & 0 & 0 \\ 0 & 0 & a_{43} & 0 & 0 & a_{46} \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & b_{33} & 0 & 0 & b_{36} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}; \mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ l_4 \end{bmatrix} \tag{6.14}$$

Again we see the problem that we cannot get the same set of prices as in the situation where we already know the valued exchanges, because services are not represented anymore. Hence here the waste disposal company seems to produce nothing, and thus cannot get any positive rate of profit, if we just look at its physical production. It could be possible that a sector shows a rate of profit equal to zero, for instance if we try to represent the public sector. However, it is of course possible that a capitalist industry is in charge of the waste disposal sector, and then real prices will differ from prices that we can calculate just looking at physical exchanges.

Hence we cloud state a second proposal in order to avoid such problems:

Proposition 3. *A capitalist industry must produce a commodity or a service.*

A corollary of Proposition 3 is that the question of waste, in the value system, is not a question of joint production. If there is free disposal, the waste does not appear in the exchange value system, and if disposal is costly, the disposal service could appear as a new good, but never the waste. However, joint production arises as soon as there is recycling of the waste (see subsection 6.2.3.2). Proposition 3 then leads to an other proposition:

Proposition 4. *Waste is not a commodity with a negative price: it is a material*[5] *artifact without price, which is not sold and thus which must not be represented in the value system.*

But then Proposition 2 must be replaced by a more precise formulation:

Proposition 5. *A resource or a service must be produced (i.e. at least some labor must be consumed in order to get the commodity) and sold in a market in order to get a price.*

Of course a more complete figure would be to acknowledge that all industries are producing wastes (and not just industry 3). Hence the system could be, with costly disposal of all wastes and industry 4 selling the service of waste disposal (it could also be that several industries are needed to dispose of the different wastes):

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & a_{13} & a_{14} \\ a_{21} & 0 & a_{23} & a_{24} \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & 0 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ 0 & 0 & 0 & b_{44} \end{bmatrix}; \mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ l_4 \end{bmatrix} \tag{6.15}$$

6.2.3.2 Recycling

It is to be noted that the case of waste, and more precisely of recycling, is touched upon by Sraffa:

> "if the scrap (metal, timber, etc.) is interchangeable in use with some other material already accounted for, it simply assumes the price of the latter without need of an additional process; if it is not completely interchangeable (e.g. scrap iron as compared with pig iron), then there will be room for two processes, producing the same commodity (e.g. steel), but differing in the proportions in which they use the two types of material" (Sraffa, 1960, § 74).

[5]There could be no "wasted service".

We could therefore introduce the recycling of the waste produced by process 3 into raw material (commodity 1). Two possibilities then arise: or the recycling is done by process 3 or by the waste disposal company (process 4). In the first case, if the recycling is directly done by the process which is producing the waste, and if all the waste is recycled, there is no need for the waste disposal company (process 4) to exist. Thus the system becomes:

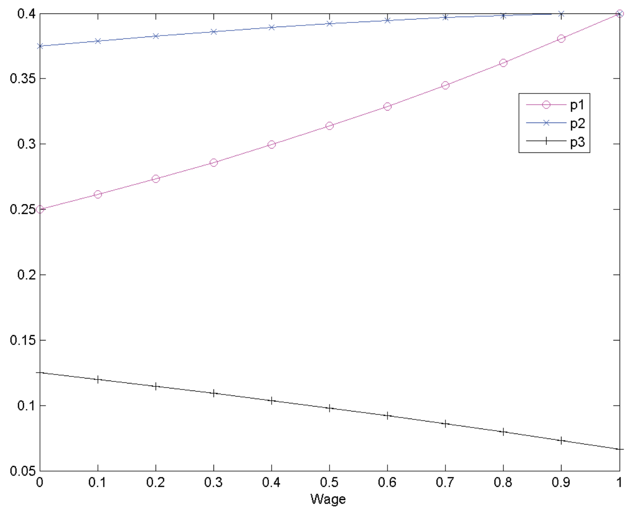
$$\mathbf{A} = \begin{bmatrix} 0 & 0 & a_{13} \\ a_{21} & 0 & a_{23} \\ 0 & a_{32} & a_{33} \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 \\ 0 & b_{22} & 0 \\ b_{31} & 0 & b_{33} \end{bmatrix}; \mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \end{bmatrix} \tag{6.16}$$

We see that we have joint production in process 3. A numerical representation of a standard system of this type could be:

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 2 & 0 \\ 1 & 0 & 6 \end{bmatrix}; \mathbf{l} = \begin{bmatrix} \frac{1}{3} \\ \frac{1}{3} \\ \frac{1}{3} \end{bmatrix} \tag{6.17}$$

The evolution of prices depending on distribution is then the following:

Figure 6.3: Evolution of prices depending on distribution



In the second case, where the waste disposal company recycles the waste, the input-output representation becomes:

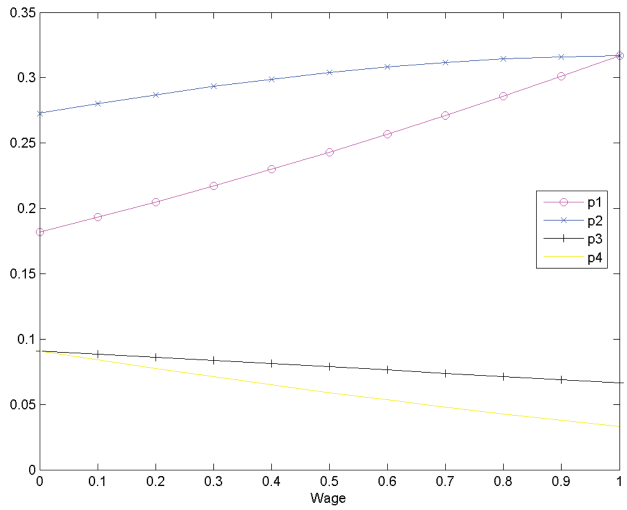
$$\mathbf{A} = \begin{bmatrix} 0 & 0 & a_{13} & 0 \\ a_{21} & 0 & a_{23} & 0 \\ 0 & a_{32} & a_{33} & a_{34} \\ 0 & 0 & a_{43} & 0 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} b_{11} & 0 & 0 & 0 \\ 0 & b_{22} & 0 & 0 \\ 0 & 0 & b_{33} & 0 \\ b_{41} & 0 & 0 & b_{44} \end{bmatrix}; \mathbf{l} = \begin{bmatrix} l_1 \\ l_2 \\ l_3 \\ l_4 \end{bmatrix} \tag{6.18}$$

As regards this last representation, we see that we have joint production in process 4. A numerical representation of a standard system of this type could be:

$$\mathbf{A} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 0 & 2 & 0 \end{bmatrix}; \mathbf{B} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 \\ 0 & 0 & 10 & 0 \\ 1 & 0 & 0 & 2 \end{bmatrix}; \mathbf{l} = \begin{bmatrix} \frac{1}{4} \\ \frac{1}{4} \\ \frac{1}{4} \\ \frac{1}{4} \end{bmatrix} \tag{6.19}$$

The evolution of prices depending on distribution is then the following:

Figure 6.4: Evolution of prices depending on distribution



6.2.3.3 Physical consequences of recycling

The inclusion of recycling can allow the system to avoid the total depletion of the stock of the natural resource: a physical analysis can be added to the value analysis. For instance, introduction of recycling can help to keep the maximal rate of profit constant, if the increase in the efficiency of recycling counterbalances the decrease in the productivity of the extraction of the natural resource. For instance, if we go back to the example of system 6.8, where extraction becomes more and more expensive, we could have now:

$$\mathbf{A}=\begin{bmatrix}0&0&1&0\\1&0&1&0\\0&1&1&1\\0&0&2&0\end{bmatrix};\mathbf{B}=\begin{bmatrix}b_{11}(t)&0&0&0\\0&2&0&0\\0&0&10&0\\b_{41}(t)&0&0&2\end{bmatrix};\mathbf{l}=\begin{bmatrix}\frac{1}{4}\\\frac{1}{4}\\\frac{1}{4}\\\frac{1}{4}\end{bmatrix} \tag{6.20}$$

With $b_{11}(t)+b_{41}(t)=2$. In this case, the maximal rate of profits will be kept constant, at 100%.

6.2.3.4 Management of pollution

In environmental neoclassical economics, pollution is considered as a negative externality, which prevents the general equilibrium to be Pareto-optimal (Guerrien, 1989; Faucheux and Noël, 1995; van den Bergh, 2002). Hence the literature tried to internalize these externalities through the introduction of quotas, taxes or tradable permits. The same instruments can be used in a neo-Ricardian framework, but as their influence on the agents or on the environment cannot be traduced in economic terms, it is not easy to compare them. Only their physical impact on the environment can be assessed, and their success should be considered regarding this criteria.

Quotas, or norms, seems to be a preferable solution: a strict physical level of pollution is allowed per industry. We could look at their impact in terms of economic production, or in the rate of profits. All other things being equal, they could lead to the diminution of the production of polluting industries, and to the apparition of greener techniques. The problem is that some industries will easily respect the norms, whereas others will have to make costly investments in order to meet the regulation. This is where a market of tradable pollution permits can help: a general quota is set for all industries (not one quota per industry), divided into pollution permits that are distributed to all polluting industries. There is the possibility to sell and buy this pollution permits. In the neoclassical theory, all industries could then equalize their marginal costs of abatement through exchanges. The problem is that the price of these permits is not fixed by a Walrasian auctioneer, but is set by the agents. Thus the probability to succeed in finding the optimal equilibrium is almost null (and the impact of the initial distribution of the permits is important, see Guerrien, 1989).

An interesting question is: what would be the price of the tradable permit in a Sraffian framework? Let us say that we have one industry, producing 10 tons of pollutant emissions each year. The quota of extraction is fixed to 5 tons per year. Hence only 5 tradable permits are given to the industry. Thus either the industry lower its own emissions to 5 tons per year (this may have an impact on the cost of production), or it will have to find an other industry willing to sell 5 tradable permits. New permits are actually given to industries that succeeds in reducing their emissions. Let us say that one company, by investing in new inputs, succeeds in reducing its emissions and receives 5 tradable permits. This company will then sell the service of environmental remediation to the first industry; a rate of profit will be applied to the initial investment, and the price of the tradable permit can be known in the usual way. Now, if several companies succeed in selling tradable permits, the price will be set according to the least profitable method, and the other methods will receive differential rents.

The other environmental policy solution is to have a Pigovian tax per unit of pollution: then, in the neoclassical theory, all industries should reduce their pollution until their marginal cost of abatement equals the tax (Pigou, 1920). The level of the tax should be set in order to minimize the social cost of pollution and the cost of abatement. A problematic assumption is that the social cost due to pollution can be measured in economic terms. Furthermore I think that the fact that pollution will decrease if a Pigovian tax is set cannot be demonstrated in a Sraffian framework. The rate of profits will decrease, or the prices will increase. This could allow a new technique, less polluting but (previously) not profitable enough, to enter the market. In order that pollution effectively decreases, it must be that substitution between the old and the new technique occurs (it has to be that the demand remains constant, and that the new technique chooses to keep its price low, so the old technique will be non-competitive). However, this new technique may not exist: thus the old technique will just continue operating. In general, this substitution may not occur, as we are in production models, and not in general equilibrium models (in the general equilibrium theory, a good will be less preferred and less used in production when its price rises - or at least, that is what neoclassical economists attempt to prove).

A Sraffian environmental policy about pollution should avoid market based policies, influenced by the idea that markets are efficient. Again, the solution lies in the close investigation of the impact of each policy on physical indicators and economic ones, such as rate of profits, wages and employment.

6.2.4 Rent on the environment

This issue is a bit different from natural resource and waste issues, that are technical and physical issues in essence. Here the problem is a distributional one. The case of differential rent could be summarised as a difference of profitability arising because of the existence of two different processes producing the same commodity. It is not necessarily related with the environment, because this rent may arise even if no natural resources are used by the two processes. If a natural resource is privately owned, and if the owner is in a position to capture a rent, he may capture the differential rent if two processes with different profitabilities use his natural resource.

However, it could also happen that the natural resource is owned, and that the owner wants to ask for a non-differential rent (or absolute rent) on the extraction of the resource. Sraffa never talks about this case (he only deals with differential rents): there are two ways to deals with it. The first is to suppose that prices are not affected by this introduction of absolute rent on natural resources. When we add the rent on process 1, depending on social relations between classes of agents, the wage and/or the rate of profit will then be lower in this industry than in the other industries. The second is to assume that prices will be affected (for instance because workers and capitalists in the extraction sector do not want to get a lower share of the surplus).

In this latter case, if the raw material is a basic commodity, the standard system will change. For instance in the case of the numerical example of subsection 6.2.1, the price system becomes:

$$\begin{array}{r}
p_3\left(1+\pi_1\right)+\frac{w}{3}+\rho=2p_1 \\
\left(p_1+p_3\right)\left(1+\pi_2\right)+\frac{w}{3}=2p_2 \\
\left(p_2+p_3\right)\left(1+\pi_3\right)+\frac{w}{3}=6p_3
\end{array} \tag{6.21}$$

With ρ the total rent. As soon as $\rho \neq 0$, the maximal rate of profit cannot be calculated independently from the prices, and thus we cannot ensure that the rates of profit are uniform. Hence there are too many unknowns for the system (3 prices and 5 distribution variables): it is only when the distribution variables are fixed that the prices could be calculated. Proposition 5 states that only goods that are produced with labor can have a price. But nevertheless some natural commodities, such as lands, are bought and sold without being produced with labor. Their prices cannot be known with the Sraffian theory: the institutional context must be defined. It is the same argument that sets the division of the surplus between profits and wages outside the realm of the Sraffian theory: these questions relates to institutions and power relationships between agents.

The question of absolute rent is important to understand why there could be a difference between real prices and Sraffian prices. If the accounting of the inputs and the outputs is correct, a possible reason for a deviation is the fact that one company asks for a greater return than it would have get normally, by putting pressure in order to lower input prices, or by increasing output prices, for instance by saying that a royalty must be paid on the extraction of natural resources.[6]

[6] Martin O'Connor (personal communication) wonders if it is possible to find, knowing the real prices, the different real rates of return, and thus to know who has the power to influence Sraffian prices in order to get an higher share of the surplus. If we come back to example 6.1, and if there is no rent on the natural resource and the wage is known, it is possible to find the rates of profit once the prices are known. If an absolute rent appears on the natural resource, we now get four unknowns (the three rates of profit and the rent) for only three equations. One of the distribution variables must then also be given from outside.

6.3 Looking at the future

6.3.1 Is nature an economic asset? Is capitalisation of nature the solution?

The UNEP (United Nations Environmental Program) recently highlights the concept of 'green economy': "a green economy is one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (PNUE, 2011). One of the core message of the green economy is that market instruments should be developed in order to protect natural resources and services.[7] These markets instruments are developed in several directions:

1. In the case of biodiversity, marketization was firstly developed through appropriation and patents (for instance on seeds), especially after the WTO agreement (part of the GATT 1994) on Trade-Related Aspects of Intellectual Property Rights (TRIPS) .
2. In the case of climate change, market mechanism are promoted, and especially pollution tradable permits (such as carbon market). Natural lands are then appropriated so that their owners can use the natural service of environmental remediation to get and sell pollution permits (for instance through the REDD+ program supported by UNEP, Sukhdev et al., 2012).
3. In the case of environmental destruction, offsetting is promoted more than avoidance or reparation (Chiapello, 2015). This leads to the appropriation of natural lands by mitigation banks in order to sell offsetting services (the destruction of an environmental site can can be offsetted by buying mitigation credits to mitigation banks, see Vaissière and Levrel, 2015).
4. And finally the notion of ecosystem services is widely developed (see the Millennium Ecosystem Assessment report, MEA, 2005) and attempts to connect an economic value to these services are developed (The Economics of Ecosystems and Biodiversity report, TEEB, 2010). This leads to the invention of several mechanisms of payment for ecosystem services, items 2 and 3 of this list being examples of what can be done in this respect: payment for the ecosystem service of carbon capture and payment for the ecosystem service of ecological compensation.

This marketization of nature is not an easy task: focusing on the 'payment for ecosystem services' concept, first nature has to represented as a set of services,

[7] After 20 years where multilateralism and UNO were at stake, now states and UNO are financially weak. This may explain why they are willing to accept market mechanism and financial evaluations of environmental actions: the goal is to attract investors into a cause they cannot support alone. The wrong side of it is that this leads to the depreciation of public and common regimes of natural resource management (Chiapello, 2015; Attac-France, 2012).

then a price has to be set on them (the 'investment in forms' is substantial in order to legitimate the process, see Thévenot, 1984). The first step can be criticized from a philosophical point of view, the second, from a economic (neo-Ricardian) one.

From a philosophical point of view, the concept of ecosystem service is a normative one. This means that the ecological service is seen as a 'good': but for whom? Is it for the society or for an individual point of view? This question does not matter if one believes that society's benefit is the sum of all individuals benefits, but this belief may not be shared by everybody (Maris, 2014, p. 34). The philosophy behind the concept of ecosystem services in the Millennium Ecosystem Assessment report and in The Economics of Ecosystems and Biodiversity report is an individualist one: each individual is the only judge of the benefit he receives from the ecosystem. Furthermore this assessment should be freely conducted: freedom of choice and action, the core concepts of liberalism, is expressed as the ultimate goods in the MEA report (Maris, 2014, p. 36). The notion of payment for ecosystem services then assumes that the benefits from these services can be valued in monetary terms (in other terms that use value be reflected in the exchange value). This entails that each ecosystem service can substituted with other economic goods, as the notion of absolute scarcity cannot be reflected in economic terms. In contrast, several philosophers argue that some values, and especially environmental values, cannot be commensurable (Brennan, 1992; Maris, 2014, p. 51).

Neoclassical economics use an individualist methodology, and promote a liberal view of society (perfectly free market being associated with optimal efficiency). They only deals with relative scarcity, and perfect substitution between factors of production and goods are usually assumed. The concept of ecosystem services, as described in the most renowned reports, is thus directly related with the neoclassical paradigm. And like the neoclassical paradigm in economics regarding other economic theories, the concept of ecosystem services captures all attention and tends to dismiss other approaches regarding the protection of natural resources.[8]

This is why, on the neo-Ricardian point of view, this concept should be rejected. This concept does not fit in the Sraffian paradigm, where use value is strictly independent from exchange value, and where exchange value appears when one commodity is produced by means of other commodities. The Sraffian paradigm, in my point of view, involves the fact that natural resources cannot have a price, as well as natural services. If a valuation of nature is required, it should be integrated into a political process, and not into an economic one. Such process should pay attention to reveal the different values attached to the environment, without attempting to integrate them into a single unit. Furthermore, it should tries to investigate the power relationships, the distribution of income, and the interests of the stakeholders, before taking a decision on the

[8]Nevertheless, worries about the efficiency of the use of the concept (Redford and Adams, 2009), about the linkage of the concept with increasing poverty and inequality (Zbinden and Lee, 2005) and about potential effects of financial developments of the concept (Wunder, 2007) are expressed.

possible valuation of the resource. This may help to avoid the commodification of nature, and the expansion of the neoclassical paradigm.

On a more formal point of view we may represent the marketization of nature in two different ways: nature is appropriated, and the owner either receives a rent on its use (renting of lands for instance, we already dealt with this case in section 4.2.4) or sells the ecosystem service that nature offers. In the second case, the price of the ecosystem service depends on the necessary investments needed to restore an environmental place (this is the service sold by mitigation banks), or to reduce pollution (this is the service sold in carbon markets). We already dealt with the price of the tradable permits of pollution in subsection 6.2.3.4: the price of the ecosystem service will follow the same logic. Its level will be set according to the least profitable method to produce the service, and other methods which succeed in selling the service will receive a rent. It may be that the investment in biodiversity offsetting is less input-intensive than investment in the avoidance of the loss of biodiversity; in the same way, investment in low-income countries in order to sell ecosystem service is surely less costly than reducing pollution in high-income countries. This may explain why payment for ecosystem services solutions are widely developed by investors (which may receives high rents) and by polluters (which want to develop more profitable techniques in order to lower the price of the tradable permits they must buy).

It must be remembered that, in this Sraffian framework, the price of this ecosystem service depends on the investment (of capital and labor) which is used to produce the service, not on the 'subjective utilitarian value' of the ecosystem service (and not on any 'intrinsic value' of the ecosystem service). According to me, there is no need to push into the direction of 'pricing the nature': what is important is to develop instruments and regulations that can effectively protect the environment. However, this could be done without asserting a price on the environment: *if nature's price is zero, this does not mean that there is a free exploitation of nature. We could imagine a system of quotas for instance, where the exploitation of nature is limited, without a change in its value (it would still be a 'free gift'). A free good does not mean that we see no value on this good: a democratic decision could have been taken stating this is the most valuable good on earth, and that no one should use it. Still, from the capitalist point of view, if it is not produced from commodities, its exchange value is zero.*

Finally another problem with these approaches is that nature becomes privately owned, and the management of nature becomes capitalized, both choices which precludes other forms of institutional management. However, this is also a claim of 'green' or 'natural' capitalism (e.g. in Hawken and Lovins, 1999) that a sustainable management implies first a capitalisation; and then a circular economy can be built. In the next subsection, the possibility of a sustainable capitalism is investigated.

6.3.2 Is sustainable capitalism possible? Is a circular economy possible?

6.3.2.1 On the economic system

The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, the 3-14 June 1992, also called the Earth Summit, accredited the idea that economic growth is the solution to solve the environmental problems, with the additional concept that the market is the more efficient tool to manage natural resources (following the idea of the 'tragedy of the commons', Hardin, 1968). The World bank and the OECD are recently promoting the concept of 'green growth', while in France the 'circular economy' is highlighted (Merino-Saum and Roman, 2012).

This concept of circular economy is highly interesting: it suggests that it could be possible to close the loop of the production process, with the possibility for each waste to be used as an input for a different industry. This approach has been investigated in the scientific field of Industrial Ecology (for an introduction of this field, see Frosch and Gallopoulos, 1989; Erkman, 1998; Ayres and Ayres, 2002 and the Journal of Industrial Ecology). But Georgescu-Roegen shows that the idea of an economy which can have no exchanges of matter and energy with its environment is not consistent (Georgescu-Roegen, 1971, 1975). Hence the idea of a sustainable circular economy should look at minimising the extraction of resources from the environment, so the environment can replenish itself: this is the idea of the steady-state economy (Daly, 1992). However, is it possible to have an infinite economic growth while keeping the economy inside the boundaries of the steady-state economy? In order to do that, we will have to decouple the production of value with the use of material and energetic inputs. Recent studies show that if a relative decoupling is feasible (we can produce more economic wealth with the same physical quantity of inputs), absolute decoupling (the decrease of physical extractions of input from the environment) may not come soon (Krausmann et al., 2009).

The question then becomes: are we still in the boundaries of the steady-state economy, or are we already at the limit? In the second case, we should stop growing (and maybe grow again when the technology will allow absolute decoupling). This question is not easy to answer, as questions about where to set the limits are political ones. But the question of growth is interesting: Pasinetti (1983) shows that growth is needed if the social system is growing; i.e. if population and consumption needs are growing. If there is not enough growth, the system will not employ enough people, and the demand will not be satisfied: the accumulation of capital answers a social need if the population and the needs are increasing. If the system produces too much, some goods will be leftover, wasted and returned to the environment: thus the management of the accumulation process is a matter of social and environmental relevance. Different types of institutions managing this accumulation should be possible, and thus need to be investigated. Unfortunately this is not allowed by the neoclassical theory (Pasinetti, 2012a), which only relies on capitalist institutions (private property, private means of production, markets) to explain the production of wealth.

If we accept the definition of capitalism from Boltanski and Chiapello (1999, p. 35), the infinite accumulation of capital is the only goal of capitalism, without any connection with social or environmental relevance. Sombart also defines the spirit of capitalism as:

> "dominated by three ideas: acquisition, competition and rationality. ... The aim of all economic activity is not referred back to the living person. An abstraction, the stock of material things, occupies the center of the economic stage. ... There are no limits to acquisition, and the system exercises a psychological compulsion to boundless extension" (Sombart, 1930, cited in Chiapello, 2007).

Hence accumulation is needed in a capitalist economy. In a context of competition, a pressure to cut costs in order to be competitive can be compatible with a more efficient use of natural resources, and thus we could observe relative decoupling between the production of economic values (exchange values) and the use of natural resources. However, this pressure to be competitive can also lead to an increase of production if we observe increasing returns to scale: thus absolute decoupling will not occur. And if the population is not growing anymore, the capitalist movement will encourage the growth of consumption, thus also to the detriment of sober, environmental-friendly, way of life.

This should encourage us to look at other institutional frameworks than capitalism, and to other theories than the neoclassical one, in order to explain and investigates the possibilities to create a steady-state economy. The Sraffian framework appears to be open to this kind of development, as it describes an economy composed of industries which sell commodities to each other and to consumers, without making any hypotheses about the process deciding how the surplus is shared, and how investments are done (at which level, in which industries). It is still a capitalist economy in the sense of Burkett (2006), because there is one unique price for each good, and because workers receives a uniform wage per unit of labor according to the quantities of labor performed (and after a process of normalisation of the quantities of labor between low and high qualified jobs. But it could be a state capitalism, where all process of production are in the hand of the State, for instance. And this kind of economy could be at odds with the definition of capitalism as an infinite accumulation process.

In this way, the Sraffian framework can help us to consider what could be a steady-state economy, where the process of accumulation is strictly controlled in order to satisfy the needs of the population and the need of the environment to be replenished. The vertical integration analysis developed by Pasinetti (Pasinetti, 1988a, 1993; Garbellini, 2011), for instance, can help us to see precisely where and how investments can be made in order to change the structure of the economy. Depending on the evolution of consumption and technical progress, this analysis helps to calculate the 'normal rates of profits' which will allow the system to reproduce itself, with full employment. For instance, if the institutional framework is able to control the evolution of technologies and the evolution of consumption which is necessary to limit extractions of natural resources and polluting emissions under the level of replenishment of the environment, we can know the investments that are needed at each period of production.

6.3.2.2 On the physical system

In the analysis of Pasinetti, the value system is only concerned with commodities and services that receive a price: thus we cannot know if this economy is a circular one (in the sense of a system of production which does not need resources from the environment and which is not emitting any pollution). Actually the notion of mass and energy balance (inputs equal outputs) or closure (there is no physical exchange with the environment) is not relevant for this kind of systems, as soon as the concept of service is introduced (or if some inputs are not produced or some outputs are not sold). To apply these notions, the physical system must be made distinct from the economic one: the first one is only concerned about exchanges of material and energetic resources, while the second one is concerned about exchanges of commodities, services and labor. Now that this distinction is clear, we can understand that a system can be circular in the physical system but producing nothing in the economic system (like the physical system of earth before the human reign), the reverse being that a process producing nothing in the physical system, e.g. a service, could produce value in the economic system.

It could be interesting to focus on the physical system only. The works of O'Connor and Andrew (2009) on the mathematical conditions for a physical system of production to be self-sustainable (with mass and energy closure at the level of the system) are relevant in this context. They show that strict requirement for the exchanges are needed if we wish to get "indefinitely sustainable 'full resource utilisation' time paths" (O'Connor and Andrew, 2009). They particularly investigate the notion of basic process: if a physical system is to be self-sustainable, it must be composed only with basic resources[9] and basic processes. 'Non-essential' and 'non-supportable' processes can then also be defined for the physical system (O'Connor and Andrew, 2009). Finally they attempt to define a methodology that could transform any random system into a self-sustainable one.

A good question is then: is the concept of standard system also interesting in the physical one? Unfortunately Dupertuis and Sinha (2009) show that this concept is purely economic:

> "It should be noted that the reduction of any given system to a system of only basic goods transforms a physical system into an economical system. For example, in §59, pp. 50–51, Sraffa (1960)

[9] I am not using the term commodities as we are talking with a physical system, and not with a value system.

> takes an example of a physical square system with four goods with two goods 'b' and 'c' produced by one process only but while 'b' does not enter in the production of any process, 'c' enters into all the four processes. Clearly 'b' in this case is non-basic and removal of 'b' from the system requires removal of the process that produces 'c'. This changes the status of 'c' in the system completely. It is now something akin to land, which enters into production on the input side but not on the output side. Therefore, 'c' has to be removed from the system of basic goods by applying appropriate positive and negative multipliers on the processes to eliminate 'c' from the system, which reduces the system of basic goods to a 2x2 square system. Though it is true that in the real system 'c' is a commodity and is necessary for the production of all the four goods, its economic status in the economic system of only basic goods completely changes. Similarly, in an economical system a process may stand with negative multipliers. Although it is not possible for any physical system to have negative multipliers, in an economical system, as Sraffa has indicated (1960, §56, p. 48), negative quantities can be meaningfully treated as debts" (Dupertuis and Sinha, 2009).

Hence again we see that the physical system and the economic system are not the same, and must be analyzed through different lenses. The Sraffian methodology can however be used to investigate the impact of the consumption of a commodity of service on the use of a natural resource: this is made by Alcántara and Padilla (2009) and Butnar and Llop (2011), using the vertical integration analysis developed by Pasinetti. This investigation can help to see what are the levers that can be used in the production or in the consumption process in order to decrease our impact on the environment. A vector of extraction (or emission) per unit of output can be defined for each industry, and then the vertical integration reveals all extraction or consumption connected with the consumption of one unit of a commodity. A link between the value and the physical system can then be drawn when the economic impact (in terms of the value produced, the maximal rate of profits, the employment, etc.) of each solution is assessed. A multi-criteria decision process can then be used to decide which solution should be implemented.

Chapter 7

Conclusion

7.1 Sraffa and ecological economics

Ecological economics, as a field of study, can be defined as multidisciplinary and receptive to pluralism and heterodox visions (Burkett, 2006, p. 2). As Røpke (2005) noted, the field is organized around strong core beliefs but its boundaries are not well defined and the methods to answer those core beliefs can originate from different, and sometimes opposite, paradigms. There have been some contributions arguing that the neo-Ricardian framework, following the seminal work of Sraffa (1960), could be one of them. After a reminder of what have been the originality of Sraffa's proposal in section 7.2, a critical review of these papers is conducted in section 7.3. Some papers from neo-Ricardian authors show their interest in environmental questions: a review of this literature is done in section 7.4. The key findings of this research for neo-Ricardian inputs for the ecological economics field are then summarized in section 7.5, before some concluding comments in section 7.6.

7.2 Sraffa's proposal

Sraffa's analysis is intended as a prelude to a critique of the neoclassical theory. This critique is done at three different levels:

1. On the analytical level, Sraffa demonstrates that, in a production system which must reproduce itself, with all processes which needs human labor, there is always a decreasing relationship between the wage and the rate of profits, under the condition that the standard numeraire is used. Furthermore, if there is no joint production, he shows that this decreasing relation becomes linear. Thus the part of the neoclassical theory concerning production and distribution is attacked: the revenues of the different factors of production do not depend on their marginal productivities and their marginal demands. He also warns that comparison of prices between two different systems of production is meaningless (there is no constant standard of value, Sraffa, 1960, § 93). This warning also holds for the neoclassical theory (see Guerrien, 1989).

2. On a methodological level, Sraffa refuses to introduce expectations and subjective data in his model. There is no assumption on the dynamics of the system, as there is no assumption on constant returns to scale, and no assumption on the behavior of the agents of production. He shows that there is no need for a market equilibrium where supply meets demand to construct the prices. He thus argues against the neoclassical methodology based on subjective preferences, rational optimization and perfect knowledge of the future from the agents.

3. On the level of history of thought, Sraffa's analysis calls for a return to the classical political economy, where the center of the analysis is to understand how to reproduce the system and how to allocate the social surplus. This is a completely different paradigm than the neoclassical one: there is scarcity only in the case of non-produced resources, such as natural resources. All the rest can be produced in order to answer the necessary needs to achieve human well-being, which can be defined in absolute terms (whereas in neoclassical theory everything is relatively scarce, because humans are never satisfied - thus growth is the only possibility to increase human well-being - see Martins, 2013 on this point). Moreover there is no connection between use-value and exchange value, as the latter depends on the conditions of production and on the distribution of the surplus (whereas in the neoclassical theory, in a free market, prices express the marginal use value of the commodity). And finally there is always the possibility to reduce "prices of every commodities into a sum of profit weighted quantities of labor" (Pasinetti, 1973), even in case of joint production, and thus to link Sraffa with the political economy of Smith, Ricardo and Marx, where, in a capitalist system of production, human labor is the substance of exchange value.

Sraffa's methodology starts by observing the quantities of commodities that are produced and exchanged in the market during a given period of production (usually a year), as well as the quantity of labor used by each industry. He deduces from these the prices. Prices are these exchange ratios that ensure that the process of production can be repeated, and that the given distribution of the surplus between profits and wages is respected, with the convention that the rate of profit is uniform. There is actually a unique set of prices because he assumes that all processes are interdependent, i.e. there is at least one basic commodity needed directly or indirectly for the production of all commodities.[1,2]

It is important to understand that Sraffa describes a capitalist system of production: owners of processes ask for profits, workers sell their labor force and receive wage. Commodities are exchanged in a market at the end of the period of production and each receive a unique price. The price assessed by the owners should allow them to buy new inputs for the next period of production (including labor) and to receive a profit, which is a part of the surplus produced by the economic system. Following this, in Sraffa's methodology, there is a price for a good or a service only when one agent of production produces it with some human labor and sells it on the market. He is thus claiming that he wants a return on the good or the service he is producing. If nobody claims for a return, the good does not appear in the equations of production, and thus no price can be assessed on this good. This is why a common critique in ecological economics about Sraffa's system, arguing that he is violating the physical laws of mass and energy conservation (Patterson, 1998; Christensen, 2005), is not relevant. Sraffa's system is designed to represent only exchanges of produced and marketed commodities and services, and not to represent physical exchanges between industries.

[1]Sraffa only differentiate between two types of commodities: basics, which are needed directly or indirectly for the production of all goods, and non-basics. The same distinction can be found for the processes. If no basic commodity can be found for the system, it means that at least two different systems of production (and thus two different price system) are juxtaposed.

[2]And this interdependence also explains why Sraffa's theory is not a cost of production theory: "it is desirable at this stage to explain why the ratios which satisfy the conditions of production have been called 'values' or 'prices' rather than, as might be thought more appropriate, 'costs of production'. The latter description would be adequate so far as *non*-basic products were concerned, since ... their exchange ratio is merely a reflection of what must be paid for means of production, labor and profits in order to produce them - there is no mutual dependence. However, for a basic product there is another aspect to be considered. Its exchange ratio depends as much on the *use* that is made of it in the production of other basic commodities as on the extent to which those commodities enter its own production ... A less one-sided description than cost of production seems therefore required. Such classical terms as 'necessary price', 'natural price' or 'price of production' would meet the case, but value and price have been preferred as being shorter and in the present context (which contains no reference to market prices) no more ambiguous" (Sraffa, 1960, § 7).

7.3 Critical review of literature in ecological economics

This literature[3] can be divided into three parts: first, a big part of the literature, dedicated to the "valuation of nature" debate. Second part about, some researchers attempt to develop a neo-Ricardian approach of ecological conflicts. And then several works about the use of the neo-Ricardian knowledge in the analysis of physical interdependence between processes, in particular for the assessment of CO_2 emissions.

7.3.1 The "valuation of nature" debate

Sraffa was first used, in the ecological economics literature, as a way to construct prices when the neoclassical theory could not do it. I refer here to the large part of literature on ecological prices, and specifically on the energy theory of value. Authors arguing for the pricing of nature could be separated into two camps: those who think that Sraffa's method could be incorporated into the neoclassical framework, and those who see it as a complementary approach to neoclassical theory - both camps do not seem to acknowledge that Sraffa's first intention was actually to attack the neoclassical theory.

In the first camp, authors (a non exhaustive list of their works could be Costanza, 1980; Costanza and Neill, 1981, 1984; Costanza and Hannon, 1989; Hannon, 1998; Farber et al., 2002; Sciubba, 2005; Winkler, 2006) start from the position that a price is not yet defined on the environment because nature is not privately owned, but that pricing the environment would reveal both its relative scarcity and its marginal use value. As a consequence, they assume that the market can correctly manage environmental resources as soon as they receive a price. In the second camp, authors (a non exhaustive list of their works could be Perrings, 1987; Judson, 1989; Patterson, 1998, 2002; Patterson et al., 2006; Kemp-Benedict, 2014) do not think that ecological price could reveal the marginal utility of natural resources and are more skeptical on the benefits of the market solution. Nevertheless they assume that it would help the protection of natural resources if a price is calculated on them through Sraffa's method. They argue that it would help to account for specific natural resource's contribution in the reproduction of ecosystems and in the production of economic wealth. For instance,

> "it is unlikely that the value of protozoa in the ecosystem would be measured in a [Willingness-To-Pay] survey, whereas in ecological pricing, the value of protozoa in the ecosystem would be taken account of by the ... linkages they have with other components of the system" (Patterson, 2002).

Sraffa's theory gives both camps the possibility to build a theory of ecological prices even without a market, because we can represent physical exchanges

[3] I am referring to authors writing in the Journal of Ecological Economics, or specifically writing about the ecological economics field, and at the same time referring to Sraffa.

within environmental processes, and between economic and environmental processes. In order to set prices on natural resources, they first insert natural resources and processes into the equations of production. They then include a "primary input" which is not produced by the system: usually this primary input is solar energy (e.g. in Costanza, 1980; Costanza and Neill, 1981; Costanza and Hannon, 1989; Hannon, 1998) but it is possible to have several primary inputs (e.g. in Patterson, 1998, 2002). And finally they calculate the exchange ratios that ensure the reproduction of the system. If the non-produced input is energy, the prices are said to reflect the energy embodied in each commodity. The problem of this methodology is threefold. First, nature does not function as a capitalist system of production, thus the analytical framework is not easily justified. Second, Sraffian prices do not reveal the importance or the "true value" of one input, so this framework leads to a result which is not in agreement with the goal of these authors. And finally, the political economy of the Classics, revived by Sraffa, must be abandoned if nature is introduced in the system of production.

On the first point, if one wants to express the prices in a Sraffian system with ecological processes and ecological resources, he has to represent the environment as a set of capitalist processes of production, in the sense that natural processes are privately owned by agents who sells natural resources on the market as commodities, with a unique price set on each natural resource. This capitalist vision of nature has been criticized by several authors (Daly, 1981; O'Connor, 1993b; Burkett, 2003, 2006): this is a simplistic view of nature, a view that can allow for the capitalist appropriation of nature, and furthermore, a capitalized nature does not ensure that the economy will be more sustainable (see especially O'Connor, 1993b on this point). Furthermore, the value of the non-produced inputs must be equal to the value of the surplus (as there is no profit in ecological pricing models). It actually means that the distribution of the surplus is fixed: it is entirely given to the "owners" of the non-produced inputs. Alternative distributions are not tried in these models, and thus their influence on the value of nature is not tested, which is related to the second problematic part.

Indeed, the second part of the problem with this representation is that it tries to express the true value of nature from the economic point of view, or the importance of one input (for instance solar energy) for the production of economic goods. But Sraffian prices represent the exchanges needed to reproduce the system of production and to distribute the surplus according to a given rule: they do not express the importance of one commodity for the reproduction of the system. Actually, in a set of basic commodities (and nature is usually represented as a set of basic process, with the economic processes using the outputs of natural processes in order to produce the economic surplus), if one commodity disappears, the system will collapse (so all commodities are equally important, even if their prices may differ). Of course, it is truly important to understand the linkages between natural resources and between nature and the economy - physical input-output analysis could help to do that. However, drawing an economic theory based on the importance of this link is extremely perilous,[4] and it is not possible if one wants to remain in the Sraffian framework. The different methods attempting to assess the importance of nature for the process of exchange value creation using a neo-Ricardian framework (Costanza, 1980; Patterson, 2002; Kemp-Benedict, 2014) are actually representing the result of a specific political decision about the valuation of nature and about the distribution of the surplus.[5]

Finally it must be understood that the inclusion of nature into the Sraffian framework means that the classical political economy of Smith, Ricardo, Marx and Sraffa cannot apply anymore: the exchange value (the prices) cannot be reduced to a dated quantity of labor anymore. With this inclusion, the natural processes produce some exchange value, and their owners can sell them and earn a revenue without producing anything, and without exploiting any labor force. It is not a neoclassical vision, because use and exchange value are still separated (and these neo-Ricardian models only calculate exchange values). But it is a step further in the direction of the idea that property of natural capital can be a source of revenue. This idea is clearly against the Sraffian paradigm, which is equivalent to the classical one, where labor and nature are the source of wealth (use value) whereas labor is the sole source of exchange value.

7.3.2 Other Sraffian approaches in ecological economics

Two other Sraffian approaches in ecological economics are interesting.[6] A first part of the literature tries to develop an ecological political economy, with a focus on ecological conflicts (a non exhaustive list of their works could be England, 1986; O'Connor, 1993b; Martinez-Alier, 1995; Burkett, 2003; Stahel, 2005; Burkett, 2006; Douai, 2009; Martins, 2013; Harribey, 2013). The goal is to represent the society as a place where conflicting systems of value compete and where power relationships play an important role in order to assess the

[4]Already one century ago, Ostwald argued that a strong relationship existed between the use of energy and economic growth, but warned that "we would err if we measured value only in proportion to the amount of free energy" (Ostwald, 1908, p. 164, cited in Georgescu-Roegen, 1979).

[5]We can relate this attempts to Ricardo's argument against Lauderdale's idea that if water becomes the exclusive possession of an individual, then national wealth would increase (Ricardo, 1817, reported in Douai, 2009). Ricardo answered that, as human production has not changed, the national wealth will just be distributed in a different way. Hence the price of water will only express this different distribution, and not the part of national wealth that can be related to the use of water. If water is a basic commodity, the whole national wealth would disappear if the use of water were to be stopped.

[6]For the sake of completeness, several other works tries to integrate some parts of the Sraffian framework into ecological considerations. Kemp-Benedict (2014) describes also a vertically integrated structure of an economy, but this time the goal of the representation is to highlight aggregated markups, on labor on one hand and on rent from the exploitation of natural resources on the other hand, and to deduce some observations about taxes on rents, natural resource productivity and resource return on investment. Kratena (2008) describes an input-output economy where environmental remediation leads to the apparition of differential rents between the different industries of one sector. We can also cite Cogoy (1995) which discusses the impact of the privatisation of the process of consumption.

dynamics of the economic production. This representation leads to questions about who are the agents of production claiming for a return on the environment, or stated differently, who are the relevant social actors which defend the environment (England, 1986; Martinez-Alier, 1995). The value of nature cannot be reduced to a quantity of exchange value, but a price on natural resources is sometime needed, for instance when reparation for an environmental damage is asked. The level of this price is the result of political decisions (Which kind of values are we taking into account? Who are the relevant stakeholders? Should we take into account the future generations? etc.), and depends on the power relationships between the social actors included in the debate. There is an acknowledgment that a deliberation able to express all different systems of value could help to solve ecological conflicts. They connect their works with the classical economy of Ricardo and Marx, but also with the capability approach developed by Sen (1999, see the work of Martins, 2013 on this point).

The second part of the literature follows a completely different track, centered on physical exchanges and subsystem analysis. On one hand, Baumgärtner et al. (2001) show that the concept of joint production could be relevant to express the fact that the production of goods is always associated with the production of wastes. On the other hand, a subsystem is defined by Sraffa in Appendix A of his book (Sraffa, 1960):

> “a system can be subdivided into as many parts as there are commodities in its net product, in such a way that each part forms a smaller self-replacing system the net product of which consists of only one kind of commodity. These parts we shall call 'subsystems"'.

A subsystem represents then all the quantities needed to produce, directly and indirectly, one specific commodity or a group of several specific commodities. The construction and the analysis of these subsystems have been investigated by Pasinetti (1973; 1988a) in order to understand the dynamics of a system of production. His decomposition of a system into vertically integrated subsystems is used by Alcántara and Padilla (2009) in order to investigate the induced emissions of CO_2 on all sectors of an economy due to the consumption of one specific commodity - they take as an example the service sector in Spain. This analysis of emissions per subsystems is deepened by Butnar and Llop (2011), who study the determinants of changes of CO_2 emissions on the subsystem level, through structural decomposition.

7.4 Critical review of literature in neo-Ricardian economics

All authors attempting to connect Sraffa with ecological economics come from the ecological economics field or the Marxist one. As a consequence, it is not possible to say that a connection exist between neo-Ricardian authors and authors in ecological economics. Nevertheless, among the neo-Ricardian school, some authors try to develop a Sraffian environmental approach.

Sraffa touches upon the subject of natural resources in his book. Natural resources are not produced by human labor therefore they do not receive a price, but if they are privately owned and in short supply, their owners can receive a rent, i.e. a share of the total value of the surplus. His model allows for the assessment of differential rents, when natural resources are of different qualities. He left entirely open questions about the ways the changing availability of natural resources and services could influence the price system and the distribution of the surplus. Among the contributions that tackle this problem, some attempt to assess the waste treatment problem and how to take into account recycling in a Sraffian framework (Hosoda, 2001; Kurz, 2006); others take into account the pollution of a natural resource and to implement a polluter-pay principle in a Sraffian model (Quadrio Curzio and Pellizzari, 2003); and others describe the management of renewable resources, when their extraction could lead to their extinction (salmon model in Kurz and Salvadori, 1995, fish farming vs. fish in the wild in Erreygers, 2014). Furthermore a debate has arisen about the good way to take into account depleting resources, and especially how a royalty on the extraction of non-renewable natural resources could appear and how to properly assess the level of that royalty (Kurz and Salvadori, 2000; Bidard and Erreygers, 2001a; Schefold, 2001; Parrinello, 2004; Ravagnani, 2008).

These contributions are sparse and do not reveal a coherent and stable set of models. Nevertheless some works are deeply conducted (Kurz and Salvadori, 1995; Quadrio Curzio and Pellizzari, 1999) and they show an interest, even diffuse, from the neo-Ricardian field for environmental questions. The main problem from these contributions is that they insert one assumption (system equilibrium) which contradicts the way Sraffa was thinking. Sraffa never says that he studied equilibrium systems: he studies real systems of production, which are rarely at equilibrium. However, the fact that he assumes a uniform rate of profits leads some researchers to deduce that he is only interested in stable, long term situations. This is denounced by Sinha (2012): this uniform rate of profits is just a convention that helps to reveal the fact that the rate of profits is a physical phenomenon (and not a price phenomenon like in neoclassical general equilibrium models) and, consequently, the fact that the rate of profits and the wages are the results of a political decision about the distribution of the surplus.

Why this is important for environmental questions? Because assuming that Sraffa's system is in equilibrium, incomes on natural capital can be justified.

The idea is that, at equilibrium, all capitals have been invested so that every capitalists earned the same rate of profits. If one could have won the equilibrium rate of profits by selling his natural capital, the only reason why he would not have done it would then be that he has already received this income in the form of royalties on natural capital. Hotelling's rule on exhaustible resource can then be justified (Hotelling, 1931).[7] However, if the system is not at equilibrium, royalties on natural resources are not justified anymore. Each sector may operate with a different rate of profits, and each time this rate is the result of a political decision about the distribution of the surplus. And if there are absolute rents in the case of natural resources in the real world (such as royalties on exhaustible resources), they are the result of a political decision, not the equilibrium income for the ownership of a capital.[8]

[7] The assumptions on which Hotelling's rule is based are: the exhaustible resource is privately owned; the owner wants to maximize the present value of his future profits; the market rate of interest γ expresses the average degree of impatience in the economy and it is equal to the society's rate of time preference; there is perfect competition; the quality of the resource is uniform and constant at any time; the stock of the underground natural resource is known; there is perfect foresight with respect to demand for the resource; it is possible to calculate the present social value of the resource, i.e. the total value enjoyed in present and future periods by the consumers of the resource; and finally, quantity produced and price $p(t)$ depend on demand and supply functions of the resource. Given these assumptions, the resource price that maximizes the present social value, when there is no extraction cost, is given by: $p(t) = p(0)\, e^{\gamma t}$. This is the price of the resource in the ground, also called 'scarcity rent' or 'royalty'. This royalty should be added to the extraction cost in order to find the price of the extracted resource.

[8] The case of differential rent on natural resources is a different one: a differential rent arises as soon as two different processes, with different profitabilities, produce the same good. This is due to the hypothesis that each commodity can only receive one unique price. This assumption could of course be discussed: when a more profitable technique is introduced, usually the price of the commodity produced by this new technique is lower than the price of the commodity produced by the older technique, in order to attract new consumers.

The differential rent may be appropriated by the owner of the natural resource, but the rent may also be distributed to the owner of the more profitable industry, or to the workers, etc. Many different institutions may can ensure that a unique price is received by each commodity. Furthermore, a differential rent may arise even in industries that do not directly use a natural resource.

7.5 Key findings

Sraffa's model was intended to criticize the neoclassical approach, and to offer a method, with classical inspirations, for the analysis of economic exchanges and the creation of exchange values. What would then be Sraffian ecological economics?

1. Firstly, the economic system, and thus the economic discourse, would only concern activities that produce, with the help of human labor, marketed commodities and services.

2. Inside this system, the cost of protecting the environment can be well defined: it represents the sum of the exchange value of all marketed services that protect the environment. This covers all activities attempting to avoid, reduce and compensate the damages on the environment. For France, this amounted to 47.2 billions euros in 2013 and that was equivalent to 2.2% of France GDP (CGDD, 2015). But this is not the exchange value of the environment: the value of the environment is not reducible to this amount of exchange value, precisely because the economic discourse is strictly reserved to marketed commodities produced by human labor.

3. Still inside the economic system, the impact of the loss of an environmental resource or service can be investigated. First, from the static analysis available for the present period of production, the dynamics of the system should be assessed (assumptions about returns to scale, introduction of different technologies, changes in demand). The impact of the environmental loss can then be known, in terms of maximal rate of profits that can be achieved, or in terms of the amount of consumption goods that can be produced. It must be reminded that comparison of prices are useless as soon as the standard system is changed; in this case the analysis must remain at the physical level.

4. Finally, inside the economic system, the impact of an environmental economic policy can be assessed. The comparative advantages of taxation (which introduces a different way of distributing the surplus) over the introduction of norms and quotas or over the introduction of a market of pollution permits can be investigated. In the first case, the analysis can focus on the level of the tax, on the impact upon the rate of profits and the different prices.

5. As regards that is outside of the economic system, nothing can be said by using the economic discourse. This means that the environment cannot be included in Sraffa's economic system, and thus we cannot know the exchange value of the environment. However, this does not mean that the environment and the economy are two disjoint spheres. The economy is embedded into the environment and this is precisely why the economic discourse cannot reach the environment. More correctly, the economy is

first embedded into the social sphere: the exchanges of marketed commodities and services produced with human labor are only a part of all exchanges that happen in the social sphere. Every-day communication, production and exchange of non-marketed goods are not part of the economic system. And political decisions about the distribution of the surplus influence the economic values. The social sphere then includes, and influences, the economic sphere. After that, all human activities are supported by exchanges with the environment; thus the human society itself is embedded into the environment. This reasoning explains why introducing the environment into the Sraffian economic system is a mistake: it would mean that nature becomes a marketed commodity, with an exchange value that cannot encompass all types of value that are associated with the environment in the social and the environment sphere. And it would mean that the economy is finally the sphere which includes the environmental sphere. This would be a complete betrayal of the ecological economics "core beliefs".

6. The economic discourse cannot apply outside the economic sphere, which is only concerned about the activities that produce, with the help of human labor, marketed commodities and services. But this activities have an environmental impact. This impact may be studied, and technological solutions or the consequences of change in demand may be investigated. The Sraffian decomposition into subsystems could be very relevant, for instance, in order to assess the environmental impact of the production of one specific good or service.

7. If the economic discourse cannot correctly translate social and environmental issues, other sciences could help to understand what is at stake: sociology, history, ecology, physics, biology, all these sciences can help to understand the linkages between the human society and the environment, and can help to assess what would be the impacts of a specific environmental management. Economic impacts could of course also be taken into consideration: but the impacts on all the activities that are not inside the economic sphere cannot be translated into the economic language.

7.6 Conclusion

Sraffa's first intention was to criticize the neoclassical marginal thinking. After thirty years of work, he only succeeded to write a prelude, but it was sufficient to generate a lot of enthusiasm about his project. Unfortunately, he did not engage himself enough in the debate following the publishing of his book. Hence some points of his thinking are still unclear nowadays, and this may explain why the neo-Ricardian school did not grow enough to really contest the neoclassical paradigm. It could nevertheless be a valuable foundation for heterodox ecological economics. It underlines that valuation is a political act, that economic valuation does not express the social wealth, and that nature cannot be seen as a produced capital.

Up to now, the major discussion about Sraffa in ecological economics was about nature's valuation. The initial assumption of researchers calculating ecological prices is that it would help the protection of the environment. This is in line with the "tragedy of the commons" notion that asserts that "the non-pricing of natural resources and the non-assignment of private or state property rights to these resources explains why they are over-exploited" (Burkett, 2006, p. 45). However, it actually promotes the ideas that natural resources should be capitalized and that the market is the only institution that could successfully manage the environment. Sraffa's analysis rejects natural resources in his explanation of exchange value, not because nature is not important for the economic process (the contribution of nature is infinite in this respect), but because the economic discourse is not able to express its value.

According to Sraffa, the economic discourse is an accounting one. Prices account for the exchanges of marketed commodities and services produced by human labor, and for the distribution of the surplus. They do not serve as incentives for production or consumption. The level of the prices is thus not really important. The central question in Sraffian economics is the distribution of the surplus: this surplus can be distributed in many ways, and the question of the fair distribution is a political one[9]. In ecological economics also, distribution is a central problem, as ecological resources and services are not uniformly distributed on the planet, and can be appropriated to the detriment of the poor[10]. Hence both schools have a central question in common, which is not the question of the value of nature, but the question of the fair distribution of wealth (ecological, social and economic wealth) between present and future generations, i.e. a political question.

This conclusion may have emerged sooner if a connection between researchers of the two fields, ecological and neo-Ricardian economics, existed. This connection may leads to fruitful results, if in both schools a clear commitment is made to develop a completely different paradigm from the neoclassical one.

[9]See Pasinetti (1993) and Garbellini (2011) for a development of a planned economy, where surplus is distributed in a way that full-employment is guaranteed and evolution of demand is satisfied. See Martins (2013) for a development of a planned economy, where surplus is distributed in a way that fulfillment of basic capabilities is guaranteed

[10]See Martinez-Alier (2002) for a study of ecological conflicts.

The neoclassical paradigm computes the exchanges needed for the maximisation of the needs and desires of the agents, in the present and in the future. A price is set on every good that needs to be exchanged and the level of the prices is important: if it is different from the optimal one, some agents would loss some utility. In this paradigm, it is then really important to set a price on nature. But the neoclassical paradigm forgets the political question: the initial distribution of the goods (ecological, social or economic goods) is not questioned.[11] The neoclassical paradigm thus appears to be a useful tool for the economically dominant class.

The reborn of classical economics is a source of interesting developments for sustainability and political economics and this is why ecological economics authors should definitely pursue their Sraffian interest.

[11]Though, it must be: arguing that every good needs to receive a price leads to the question of the ownership of these goods.

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