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# Sraffa and ecological economics

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References to Sraffa and to the neo-Ricardian school is something quite customary in ecological economics. By looking at contributions in this area since the beginning of ecological economics and at contributions on environmental problem from the neo-Ricardian school, we see that a connection between both school 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.

## 1 Introduction: 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) noticed, 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 than the neo-Ricardian framework, following the seminal work of Sraffa (1960), could be one of them. After a remind of what have been the originality of Sraffa's proposal in section 2, a critical review of these papers is conducted in this section 3. One conclusion of this review is that there is not yet a real connection between neo-Ricardian theorists and ecological economists: a link between both field still has to be built. This connection is not unrealistic as some papers from neo-Ricardian authors show their interest in environmental questions: a review of this literature is done in section 4. Then the key findings of this search for neo-Ricardian inputs for the ecological economics field are summarized in section 5, before some concluding comments in section 6.

## 2 Sraffa's proposal

Sraffa's analysis is intended as a prelude to a critique of neoclassical theory. This critique is done at three different levels:

1. First, on a mathematical level, Sraffa shows that it is not possible to determine the cost of capital independently of the prices. He demonstrates that,

under the condition that a standard numeraire is used, there is a linear relationship between the rate of profit and the wages. Thus the neoclassical theory of production and of distribution is attacked: the revenues of the different factors of production do not depend on their marginal productivity. Moreover he shows that there is no need for a market equilibrium where supply meets demand to construct the prices.

2. Second, 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 is thus arguing against the neoclassical methodology based on subjective preferences, rational optimization and perfect knowledge of the future from the agents. He is also warning that static comparison based on prices is meaningless as soon as technical change occurs (there is no constant standard of value, Sraffa (1960), § 93).
3. Third, on the level of history of thought, Sraffa's analysis calls for a return to 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, and 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 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 produced and exchanged on the market by the industries at a given period of production (usually a year), as well as the quantity of labor used by each industries, and it deduces from this observation the prices. Sraffa defines price as exchange-values in this way:

"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 re-

stores the original distribution of the products and makes it possible for the process to be repeated" (Sraffa (1960), § 1).

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<sup>1</sup>. This interdependence also explains why only one rate of profit is possible: this does not mean that the system is at equilibrium, it is just a mathematical property of the system of equations (see Sinha (2012) for a demonstration of this point)<sup>2</sup>.

Then Sraffa shows that, if there is a surplus, in order to solve the system of price, an hypothesis on the distribution of this surplus between the agents of production has to be fixed. The surplus is composed by the commodities that are not needed directly for system to reproduce - indirectly, part of the surplus needs to be consumed by the workers in order to reproduce their labor force (Sraffa thus assumes that there is always a surplus, as soon as he introduces human labor as an input for the system of production). When one of the distribution variable, the rate of profit or the wage, is fixed in an exogenous way, the price system can be solved. Sraffa's prices thus express the necessary exchanges needed for the reproduction of the system and for answering the given claims on the distribution of the surplus. Prices vary as soon as the hypothesis about the distribution variables changes.

It is important for the following of the paper to understand that Sraffa is describing a capitalist system of production: owners of processes ask for profits, workers sell their labor force and receive wage. Commodities are exchanged on a market at the end of the period of production and receive each 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 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

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<sup>1</sup> 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.

<sup>2</sup> 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, labour 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).

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 marketed commodities and services, not to represent physical exchanges between industries.

### 3 Critical review of literature in ecological economics<sup>3</sup>

This literature can be divided in three parts: first a big part of the literature is engaged in the "valuation of nature" debate. Second, some researchers try to develop a neo-Ricardian approach of ecological conflicts. And then several works try to use the neo-Ricardian knowledge in the analysis of physical interdependence between processes, in particular for the assessment of CO<sub>2</sub> emissions.

#### 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 in two camps: those who think that Sraffa's method could be included in the neoclassical theory, and those who see it as a complementary approach to neoclassical theory - both camps actually do not acknowledge that Sraffa's first intention was to attack the neoclassical theory.

On 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 at the same time 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. On 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

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<sup>3</sup> 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.

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 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. Then they include a “primary input” which is not produced by the system: usually this primary input is solar energy, as in Costanza (1980); Costanza and Neill (1981); Costanza and Hannon (1989); Hannon (1998) but it is possible to have several primary inputs, as 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 twofold: 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 of one input, so this framework leads to a result which is not in accordance with the goal of this authors.

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 (1993); 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 (1993) 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). This is understandable in the context of a capitalist production system where distribution is needed in order to sell the surplus to the agents of production. But it is much more difficult to justify this in the context of ecological production: it looks like an arbitrary assumption, as the surplus is not sold to the “owners” of the non-produced inputs (see 7).

The second part of the problem with this representation is that it tries to express the 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: 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. Of course, it is truly important to understand the linkages between natural resources and between nature and

the economy - physical input-output analysis could indeed help to do that. But drawing an economic theory based on the importance of this link is extremely perilous<sup>5</sup>, and it is not possible if one wants to stay in the Sraffian framework. The different methods trying 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<sup>6</sup>.

### 3.2 Other Sraffian approaches in ecological economics

The other Sraffian approaches in ecological economics can be separated in two parts. A first part of the literature tried 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 (1993); 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 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 defending the environment (England (1986); Martinez-Alier (1995)). The value of nature can not be reduce to exchange value, but a price on natural processes is sometime needed, for instance when reparation for a damage is asked. The level of this price is the result of political decision, 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 (Sen (1999), see the work of Martins (2013) on this point).

The second part of the literature follows a completely different track, centered on 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'”.

<sup>5</sup> 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)).

<sup>6</sup> 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. Thus 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.

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 (Pasinetti (1973, 1988)) in order to understand the dynamics of a system of production. His decomposition of a system into vertically integrated subsystems is used by Alcantara and Padilla (Alcántara and Padilla (2009)) in order to investigate the induced emissions of CO<sub>2</sub> 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 (Butnar and Llop (2011)), who study the determinants of changes of CO<sub>2</sub> emissions on the subsystem level, through structural decomposition. Finally Kemp-Benedict (Kemp-Benedict (2014)) describes also a vertically integrated structure of an economy, but this time the goal of this 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.

#### 4 Critical review of literature in neo-Ricardian economics

All authors trying 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 the neo-Ricardian authors and the authors of 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 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 the questions about the ways the changing availability of natural resources and services could influence the price system and the distribution of the surplus. On the contributions that tackle this problem, some try to assess the waste treatment problem and how to take into account recycling in a Sraffian framework (Hosoda (2001); Kurz (2006)); others to 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 to 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 (2001); Schefold (2001); Parrinello (2004); Ravagnani (2008)).

Part of the debate concerns the possible integration of the Hotelling's rule



(Hotelling (1931)) into the Sraffian framework. 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  $\gamma$  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<sup>9</sup>; 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.

These assumptions runs clearly against the criticism raised by Sraffa and the methodology he adopted. It involves assumptions on the way people behave and how they take decisions, where Sraffa only looked at the consequences of these decisions. It involves expectations about future demand, where Sraffa was only interested in the present period of production. It involves the belief that social value could be assessed through an economic reasoning, where, in classical political economy, use value and exchange value are separated. And finally these assumptions allows for the capitalization of the exhaustible natural resources, as the resource is privately owned and a claim for a price (or royalty) on that resource can be stated by the owner. The debate within the neo-Ricardian school is not closed however - some argue that Ricardo was actually close to Hotelling's thinking on the subject of exhaustible resources (Kurz and Salvadori (2009))<sup>10</sup>.

Thus there is a real interest into environmental questions in the neo-Ricardian field of research, and it could be possible to connect their works to Sraffian approaches in ecological economics. In the next section, I will draw the main lines around which this connection should be constructed.

## 5 Key findings

Is Sraffa's analysis interesting for the ecological economics field? And how to use Sraffa in ecological economics? For the first question, we can go back to the characteristics of the ecological economics field, as a multidisciplinary field, open to heterodox theories. Sraffian economics are economics, with very few openness from the neo-Ricardian researchers to other scientific fields. Nevertheless it is an heterodox stream of thought within the economic science, a different

<sup>9</sup> This assumption is later relaxed in Hotelling's model, but this is never done in the related neo-Ricardian models.

<sup>10</sup> But this argument leaves open the question about the differences between the Sraffa's and Ricardo's thoughts on that subject.

paradigm from the neoclassical one, and a genuine critique of the market framework from the economic point of view. It actually redefines the boundaries between economics, politics and ethics, as it shows that the valuation process is intrinsically a political process, a result of social choice and power relationships. As a result, it could help to support certain views on ecological economics, for instance the view developed by Spash (Spash (2012)) that ecological economics should become a more politically and ethically engaged movement.

Furthermore, the Sraffian framework is not contradictory to the core beliefs of ecological economics expressed by Røpke in this way: environmental problems are critical; we face basic ignorance in front of them so we need transdisciplinarity, pluralism and system thinking in order to grasp them; nature as value in itself; the economy is embedded in a broader social and cultural system (Røpke (2005)). If Sraffa says nothing about the first two core beliefs, he acknowledges that the economic variables are dependent on social (the political choice for the distribution of the surplus) and physical relationships (the necessary exchanges in order to produce the commodities). And he proves that prices express the allocation of private property rights on resources and processes, the exchanges needed to produce the commodities and the adopted distribution. He thus shows that prices do not express social wealth or intrinsic values of the commodities. Nature could be inserted into a Sraffian framework, but the price on natural resources will not reveal their use-values: it will just reveal the way nature is appropriated. Nature as a value in itself that can not be expressed by using exchange values.

For the second question, findings come from the debate around the value in ecological economics and around Hotelling in the neo-Ricardian field on one hand, and from Sraffa's initial goal on the other hand. We have to take into account all levels of criticism Sraffa tries to express, mathematically, methodologically and historically, in order to build a real eco-Sraffian framework. First, Sraffa's theory is non-reconcilable with the neoclassical theory. If one adopt the Sraffian point of view, he has to abandon marginal thinking, supply and demand reasoning and equilibrium assumptions. The neoclassical theory on the value of capital should also be abandoned, and thus Hotelling's rule should not be used. We have to reject as well the idea that prices reflect sustainability or utility: they only reflect the conditions of production and of distribution during one period of production.

Second we have to adopt Sraffa's methodology, starting from empirical observations of the system of production of marketed commodities. It thus appears that nature should not be included in a Sraffian framework, unless it has effectively been capitalized. In the general case, the Sraffian framework is unable to assess a price on natural resource, as it is not produced: the level of the rent that an owner of a natural resource can claim should be assessed in an exogenous way (through empirical observations, for instance). This does not involve that consequences of depletion or pollution of natural resources on the economy could not be assessed through a Sraffian framework. The physical consequences could be integrated in the physical exchanges already needed for the economic production, and thus consequences on the maximum rate of profit and on prices

could be observed. But from that kind of observations, no intrinsic value of the environment could be deduced.

Sraffa shows that no comparison of prices could be meaningfully drawn as soon as technical change is involved (no point of comparison will exist, so the value of one commodity is only relevant during one period of production). Thus 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. Thus studies on the physical properties of system of production are really important, and especially about consequences of interdependence between processes. Analyses in terms of vertically integrated sectors looks promising in this respect (see Garbellini and Wirkierman (2014) for a recent neo-Ricardian development on that subject).

And finally the analysis must be included in the classical framework of Ricardo, Marx and Sen. In classical political economy, the economy is seen as “a circular process of sustainable reproduction, where the surplus should be used efficiently, in a non-wasteful way” (Martins (2013)). Thus the classical approach, interested in the reproduction of the economic and natural systems in order to answer objective basic needs and bypass absolute scarcity, is much more compatible with sustainability analysis than the neoclassical. This approach also allows for political and ethical considerations to take part in the definition of those basic needs and the protection of nature could enters in the discussion as a valuable ethical point of view.

## 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. Thus 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 recalls that valuation is a political act, that economic valuation does not express the social wealth, and that nature can not 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 people 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). But it actually promotes the idea that natural resources can be substituted with fixed capital. Sraffa’s analysis helps to understand why natural resources pric-

ing does not account for their part played in value creation: they can be seen as basic commodities, supporting our economic system of production. Thus it is not possible to adequately calculate their contribution, as in a set of interdependent processes, if one basic commodity disappears, all processes collapse. The contribution of nature is infinite, and its price is a matter of political decision.

This conclusion may have emerge sooner if a connection between researchers of the two fields, ecological and neo-Ricardian economics, were existing. This connection may leads to fruitful results, if in both schools a clear commitment is made to develop a completely different paradigm from the neo-classical one. The reborn of classical economics is a source of interesting developments for sustainability economics and this is why ecological economics authors should definitely pursue their Sraffian interest.

## 7 Annexe: Distribution in a Sraffian framework

Sraffa's equations of production can be written in this way:

$$(1 + \pi) \mathbf{A}\mathbf{p} + w\mathbf{l} = \mathbf{B}\mathbf{p} \quad (1)$$

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,  $\pi$  the uniform rate of profit and  $w$  the uniform wage.

In ecological pricing, the usual price system is the following<sup>11</sup>:

$$\mathbf{A}\mathbf{p} + p_e\mathbf{e} = \mathbf{B}\mathbf{p} \quad (2)$$

With  $\mathbf{e}$  a column vector, which represents the coefficients of a non-produced input and  $p_e$  the price of the non-produced input.

If there is no surplus, prices express the exchanges in the market that must happened to allow the identical reproduction of the system. Thus, 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 bought by the agents of production (capitalists or workers). But now, they must be granted with a revenue (profits or wages), otherwise they could not by this surplus. Thus the value of the

<sup>11</sup> An exception is Kemp-Benedict (2014), who asserts absolute rents on natural resources extraction, and explicitly says that the level of the rent is given in an exogenous way. His goal is to express the part of GDP which is based on the use of environmental resource, as he is trying 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)). But what he is actually revealing is by how much the value of the GDP has increased when a rent on natural resources is added. An other exception is Sciubba (2005), but again with a strong assumption on distribution: in his case, energy, labor and capital are remunerated in the same way.

surplus is distributed to the agents of production, so they can buy the surplus (the question of the equality of this distribution between agents is a matter of political struggle). So equation 1 is justified from an economic point of view, in order to close the system.

In ecological pricing models, there is no profit on natural processes. Thus, if there is a surplus (as for instance in Costanza and Neill (1981); Patterson (2002)), the value of the surplus is “distributed” to the non-produced input: this is actually justified by the ecological pricing authors on the footing that the real value added comes from the sun, or from other primary inputs. But what they do not acknowledge is that this “distribution” means that the “owners” of the non-produced input are able to buy the whole surplus: the total value of non-produced inputs becomes equal to the value of the surplus. Confirmation of this statement can be found in Patterson (2002), where Patterson 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 the analytical framework. And if this analytical framework is justified in a market analysis where companies need to sell their production, it is hardly justified in ecological pricing, when there is no agents of production and no market.

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