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Who is Going to Kiss Sleeping Beauty? On the 'Classical' Analytical Origins and Perspectives of Input–Output Analysis

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ABSTRACT *The paper argues that input–output analysis existed long before it received its name and Wassily Leontief made it popular as a tool of empirical analysis and a foundation of economic policy. It grew out of an attempt to ascertain the capacity of an economic system to reproduce itself and generate a surplus that can be used for various purposes. Primitive pronouncements are encountered in early civilizations, for example Mesopotamia, in terms of the ratio of the amount of grain produced and the amount of it used up, directly and indirectly. These ideas reappeared in a more sophisticated form at the time of the inception of systematic economic analysis in the 17th and 18th centuries in Europe and found a two-sector expression in François Quesnay's* Tableau économique. *The material input–output structure was then considered the core of the economic system that contained one of the keys to basically all other important economic phenomena and magnitudes. The way in which the potentialities embodied in the input–output structure, conceived as a system of production, have, or have not, been exploited over time define both the problems and perspectives of contemporary input–output analysis. Three aspects will be scrutinized more closely: the problem of value added, the treatment of fixed capital and the problem of technical change. Happily enough, while the problems are huge, the prospects are encouraging. There is no fear that input–output analysts will soon have to look for new fields of research because the old ones have been exhausted.*

1. Introduction

I think we would all like to agree on the following description of the situation of economics:

> Economics today rides the crest of intellectual respectability and popular acclaim. The serious attention with which our pronouncements are received by the general public, hard-bitten politicians, and even sceptical businessmen is second only to that which was given to physicists and space experts a few years ago.

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Do I sense expressions of astonishment, even disagreement?

My apologies. I should have mentioned that this is what Wassily Leontief (1971, p. 1) said in his Presidential address delivered at the 83rd meeting of the American Economic Association, Detroit, Michigan, on 29 December 1970. Things have dramatically changed since. Today, economics could be said to ride the crest of intellectual contempt and popular ridicule. Scathing judgements are passed on economists. Tools are said not to be tailored to the problems tackled, but rather the other way round, with the result of large parts of the discipline living mentally in a fool's paradise. In such a world, crises cannot happen, breakdowns of the system or its parts are impossible. And now? No other discipline, if economics can properly be called a 'discipline' (recall that John Hicks was doubtful of this), has fallen as deeply into disrepute as economics. The front cover of a July 2009 issue of *The Economist* shows a book entitled 'Modern Economic Theory' that is melting down. In the issue an article attacks two fields of modern economics, macroeconomics and financial theory, which are said to be seriously flawed and to have misled policy makers. Paul Krugman dubbed the past three decades in macroeconomics as 'the lost decades'. Robert Lucas, an economist who bears a significant portion of the responsibility for the current dismal state of the 'dismal science', came to the defence of modern economic theory in *The Economist*, but all he had to offer was a declaration of his unwavering conviction that the rational expectations-representative agent models he had advocated are the right approach.

Other scientific disciplines have experienced comparable situations, in which the leading paradigm suffered a major defeat and was gradually replaced by another one. In astronomy, the Copernican view of the world was replaced by the Newtonian view. In physics, traditional mechanics had to give way to quantum physics. We do not yet know what will be the long-term impact of the crisis on economics. What is less clouded in uncertainty are the reasons for the current malaise, and I will in a few moments talk about them, with Leontief as my main witness. The questions to be addressed are these: why did economics go wrong, and when? And are there any alternatives to current mainstream economics, and, if yes, which?

It hardly needs to be emphasized that these are all questions with a strong historical dimension. How could one answer them without having some deep knowledge of the history of our subject? Now, a problem within the larger problem of today is that during the past years if not decades the history of economic analysis has been pushed to the fringe of the discipline by those who believe that economics can, and should, be shaped in the image of the 'hard' sciences, preferably physics. Here we need not be concerned with whether the image some scholars appear to have of the natural sciences stands up to close examination or whether it reflects a view that is obsolete by now, as some historians of science maintain.[1] What matters for the purpose of our argument is that the underlying concept of hard science entertained is tantamount to claiming

[1]See in this context Ilya Prigogine's (2005, p. 69) statement: 'In all fields, whether physics, cosmology or economics, we come from a past of conflicting certitudes to a period of

that science is invariably cumulative in the sense that there is progress, progress and only progress; there is never regress. The process of the production and absorption of knowledge is taken to be perfect: whatever is good and valuable will be retained, whereas whatever is weak and erroneous will be weeded out. If this was to be true, there could only be an antiquarian interest in the past: why bother about 'the wrong opinions of dead men', to use Pigou's famous phrase?

The answer is simple: what is wrong and what is right is not so easy to decide in a subject dealing with such a complex matter, as does economics. At any rate, to be wrong is not a privilege of the dead, and to be right not a privilege of the living.

When an idea, a theory or a whole discipline are in trouble, it is always advisable to look back in order to see when the car was shunted onto the wrong track. As regards one of the main reasons for the present troubles, we don't have to go far. Leontief's 1970 Presidential address contains remarkable statements, and warnings, about the wrong track economics had taken. He did not couch his disenchantment with the situation in diplomatic verbiage. He was straightforward: The 'uncritical enthusiasm for mathematical formulation tends often to conceal the ephemeral substantive content of the argument behind the formidable front of algebraic signs' (Leontief, 1971, pp. 1–2).[2] Assumptions are often chosen by mathematical convenience, 'but it is precisely the empirical validity of these *assumptions* on which the usefulness of the entire exercise depends' (p. 2). '[M]ore and more sophisticated statistical techniques' are being elaborated 'to stretch to the limit the meagre supply of facts' (pp. 2–3). 'Continued preoccupation with imaginary, hypothetical, rather than with observable reality has gradually led to a distortion of the informal valuation scale used in our academic community to assess and to rank the scientific performance of its members' (p. 3). '[Y]ounger economists ... seem by now quite content with a situation in which they can demonstrate their prowess (and incidentally, advance their careers) by building more and more complicated mathematical models and devising more and more sophisticated methods of statistical inference without ever engaging in empirical research' (p. 3). There is a 'comfortable self-sufficiency', a 'complacent feeling' around, which has led economists to believe that they can do without any 'cooperative relationships across the traditional frontiers now separating economics from adjoining fields' (pp. 3–4).

Leontief rejects vehemently the instrumentalist methodological point of view, forcefully advocated by Milton Friedman, that what matters is not the realism of the assumptions, but the realism of the results derived with its help, the predictive power of the theory. This is the only legitimation of the bold assumptions entertained in much of modern macroeconomic theory. Has it passed the test?

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questioning, of new openings. This is perhaps one of the characteristics of the period of transition we face at the beginning of this new century.'

[2]For Leontief's view of the role of mathematics in economics, see Leontief (1954). The following quotations are all drawn from Leontief (1971; emphasis in the original).

In Leontief's view, what matters is that the analysis starts from, and stays in close touch with, observable magnitudes.[3] He defines input–output analysis in the following way:

> Input–output analysis is a practical extension of the classical theory of general interdependence which views the whole economy of a region, a country and even of the entire world as a single system and sets out to describe and to interpret its operation in terms of directly observable basic structural relationships. (Leontief, 1987, p. 860)

Leontief's is as good a characterization of input–output analysis as one can possibly get, and I will take it as the obvious starting point. My attention will focus, in Leontief's terms, on

(i) the classical theory of general interdependence;
(ii) the analysis of the economy in terms of a single system; and
(iii) the interpretation of its operation in terms of directly observable basic structural relationships.

These distinctive features of input–output analysis were already spelled out in Leontief's maiden paper, 'Die Wirtschaft als Kreislauf' (Leontief, 1928), based on his PhD thesis written under the supervision of Ladislaus von Bortkiewicz at the University of Berlin.[4] These features permeate Leontief's entire body of work on input–output analysis. In the course of time some of these features gain in prominence, while others retreat into the background. Consequently, only a part of the explanatory potential of the input–output approach has been realized, while other important elements have been left dormant. In terms of the marvellous fairly tale 'Sleeping Beauty', handed down to us by the brothers Grimm, the dormant princess is still waiting to be kissed awake. Who will do her the favour?

Being risk-averse, which is the proper attitude of the prudent scholar, one will of course wish to know more about whom one is supposed to kiss (and perhaps marry), whether the enterprise can be expected to be rewarding, what kind of fortunes are in the game, etc. I shall do my best to give you an idea about these issues, as I see them, and I hope to convince you that it is worth engaging with Sleeping Beauty: great rewards are waiting for you, intellectual and other.

What I intend to advocate is a resumption of the classical approach to economic phenomena, as it was propagated by Leontief in his 1928 paper, but also in

[3]He shares this conviction with one of the founding fathers of both mathematical economics in general and marginalist (production) theory in particular and empirical economics, Johann Heinrich von Thünen.

[4]An abridged English translation has been published under the title 'The economy as a circular flow' (Leontief, 1991; it is reprinted in Kurz *et al.*, 1998). I have relied upon this translation when quoting from Leontief (1928); the page numbers cited below in Section 4 refer to the original German version of the article.

one of his last papers (Leontief, 1985). I proceed in the following way. First, I draw attention to the fact that some sort of primitive input–output analysis existed already a long time *avant la lettre* (Section 2). Right at the beginning of civilization and the attainment of some modest levels of prosperity one encounters an early form of it. And right from the beginning it was used as an instrument of economic policy. Next I spend a few lines on the classical theory of general economic interdependence, touching upon François Quesnay's *Tableau économique* and the other usual suspects (Section 3). Then in Section 4 I turn to Leontief's 1928 essay and point out how deeply it is rooted in the classical point of view, according to which the directly observable basic structural relationships of the economy also contain the key to an understanding of the problem of value and distribution. Indeed, relative prices and one of the distributive variables (the real wage rate or the rate of return on capital) can be ascertained on their basis. This is expounded in some detail (Section 5). The discussion prepares the ground for an investigation of the problem of technical change in an input–output framework, or what Leontief (1985) called the 'choice of technology'. In this paper, Leontief resumes the classical approach and demonstrates its fruitfulness (Section 6). The final Section (Section 7) contains some concluding remarks.

2. Input–Output Analysis *Ante Litteram*

As Neri Salvadori and I have argued (Kurz & Salvadori, 2000), there were a number of scholars whose writings foreshadowed and occasionally even anticipated major ideas in Leontief's seminal contributions. Let us go back to ancient times. Think of Mesopotamia, the country between the Tigris and Euphrates rivers (modern-day Iraq), when it was at the peak of its prosperity and power some four millennia ago. The main entrance to its capital, Babylon, the Ishtar gate, is known to have displayed every year a summary account of the economy's production performance in terms of units of grain, specifically barley. The information given on clay tablets was total output of barley during the year, the input of barley needed directly and indirectly to produce that output, and the surplus product, that is the difference between the output and the input of grain. The input comprised the amount of barley needed for seed and subsistence of workers, overseers and animals plus the barley equivalent of other indispensable inputs. This was a simple scheme of national accounting and it served a useful task. It informed the rulers and (literate) population alike about the amount of barley available for other than reproductive purposes. In years with good harvests this amount was huge; in years with bad harvests it was small; in exceptionally bad years it was negative. Over a succession of good and bad harvests the summary account indicated the average surplus-creating capacity of the economy and thus its capability to cater for other social needs, to engage in wars and conquests, etc.

About the economic conditions prevailing in various regions at various times, one reads:

> Average returns of barley [in Mesopotamia] . . . were towards the end of the third millennium twenty times and in especially fertile regions thirty times as much as

> the amount of seed invested, but later they dropped to lower levels (1:6 and 1:10). Compare this to the following: in classic Greece one calculates with a ratio of 1:4.5 up to 1:7, with regard to Italy, the Roman author Columella speaks of 1:4. The situation in the European middle ages were similarly bad. (Renger, 1991, pp. 188–189)

It is interesting to note that in order to provide a scalar representation of the surplus-creating capacity, all magnitudes are expressed in grain. Grain, or corn, was the 'good of goods', like bread in the Bible.[5] The Mesopotamians used a simple corn model description of their economy, with corn being produced by means of corn. Such a kind of thinking may be considered primitive, but it is in fact rather sophisticated and based on a high degree of abstraction. It did what scientists typically do: by looking at things from a particular perspective they reduce the complexity of the world to what are considered its bare essentials in order to render it understandable. The corn model survived the centuries and is with us even nowadays.

From an economic point of view the comparison between output and input becomes interesting only when we subtract from outputs the necessary physical real costs, that is, those real costs in terms of the product under consideration that cannot be avoided, given the technical, natural and social conditions of production of the economy. These costs include, of course, the sustenance of workers in agriculture as much as the sustenance of work animals used in production. With regard to a document stemming from the 21st century BC, Renger (1991) estimates the total produce of one of the southern Babylonian states as approximately 12,600 tons of barley. One twentieth of it (630 tons) constitutes seed that has to be sowed again in order to repeat the process of production (assuming unchanging weather conditions). There remain 11,970 tons, of which 7,500 tons went to the king and his court and administration and army to look after central tasks of the state. We are told that this sum represents 25,000 yearly rations of barley, each consisting of 300 kg. The difference between 11,970 and 7,500 tons, i.e. 4,470 tons, apparently gives the amount of barley in the support of those producing barley, including of course their families. Calculating with the same yearly amount of barley per family for those employed in agriculture, we find that there were altogether 14,900 people (workers and their families) employed in barley production. Using a concept introduced by David Ricardo, we may call the 4,470 tons of barley, 'necessary consumption' and the 7,500 tons social 'surplus'—the amount of the product over and above all the necessary costs incurred in the production of the gross product.

The national accounting in terms of barley therefore is:

$$\begin{aligned} &\textit{Surplus}\ (7{,}500\ t) = \\ &= \textit{Gross Product}\ (12{,}600\ t) - [\textit{Seed}\ (630\ t) + \textit{Necessary Consumption}\ (4{,}470\ t)] \\ &= \textit{Gross Product} - \textit{Necessary Input}. \end{aligned}$$

[5]Recall Sir William Petty's remark: 'Corn, ... we will suppose to contain all necessaries for life, as in the Lord's Prayer we suppose the word Bread doth' (Petty, 1662, p. 89).

If one relates the surplus to the necessary input, then one gets what we may call the net product or surplus rate:

$$\textit{Surplus Rate} = \frac{\text{Surplus}}{\text{Necessary Input}} = \frac{7{,}500t}{5{,}100t} \approx 1.4706.$$

In another paper, in which he deals with production and distribution in the state of Ebla (in the plains of Aleppo) in the middle of the third millennium BC, Renger (1986, p. 295) stipulates:

1. A human being needs a certain amount of arable land, which guarantees her provision of food during the year. This presupposes a knowledge of the need of food. I assume that a family of five needs 1,100 kg per year. . . .
2. The size of the area is based on the specific agronomical conditions of the region under discussion: the fertility of the soil (depending on climatic, hydrological and other factors) decides the level of possible returns. For Ebla I assume ca. 600 kg of barley per hectare per year.

On the basis of these assumptions plus a few further ones (concerning, *inter alia*, the breeding of cattle and sheep), Renger then estimates the population of Ebla and the approximate size of the area controlled by it. A comparison of the figures ascertained in this way and those found in the literature shows some huge discrepancies, which throw into doubt the reliability of the latter. A simple input–output analysis centred on a corn model thus turns out to be of great use in historical research.

3. Early Classical Economics

We now make a big jump—from the economies of Mesopotamia and Ebla to those of Europe, especially France and England, in the 17th and 18th centuries, when political economy was gradually stepping out of the shadow of moral philosophy (without, of course, ever completely leaving it behind) and establishing itself as an independent discipline. And once again we encounter a corn model, or rather a calculation in terms of corn, in order to describe and analyse the economic conditions of the time and place under consideration. William Petty (1623–1687) coined the famous phrase: 'Labour is the Father and active principle of Wealth, as Lands are the Mother' (Petty, 1662, p. 68). In his first major contribution to political economy, his 1662 *Treatise of Taxes and Contributions*, Petty elaborated a clear concept of social surplus, which forms the basis of his analysis of taxation and the financing of public activities. He reckoned the agricultural surplus as corn output minus necessary corn input, which includes the sustenance of agricultural workers, and set this surplus equal to the rent of land, obtained by the landed gentry (Petty, 1662, p. 43).

Petty emphasized that for a given amount of subsistence per person, the surplus could also be expressed in terms of the additional people that can be supported by a given number of workers in agriculture, given the methods of production in use. Let a be the seed input and l the labour input per ton of barley output, and let b be the amount of barley consumed per worker plus his family. A yearly cycle of production and constant returns to scale are assumed. The system is able to generate a surplus provided

$$a + bl < 1.$$

If the amount of barley consumed by other members of the society (and their families) happens to be equal to c tons per year, then the maximum number of such people that can be supported per worker in agriculture is given by:

$$\frac{1 - a - bl}{cl}.$$

Petty also put forward the idea that the observed conditions of production contained the key to an understanding of the exchange relationships between different commodities in the economy. He considered the costs of production in material terms as the main cause of what he called their ‘natural value’. The latter was seen to express the difficulty of production of an item in a given situation. What mattered according to Petty were the ‘permanent Causes’ governing the production of commodities, whereas ‘accidental values’ also reflected ‘contingent Causes’ ruling at a given place and time (Petty, 1662, pp. 51, 90). The attention ought to focus, Petty insisted, on the former and thus on the systematic and permanent factors regulating relative prices.

Leontief, we have seen, stressed that input–output analysis is concerned with ‘directly observable’ magnitudes and relationships. Two centuries earlier Petty had advocated a strikingly similar view. In a famous passage he had specified which method of investigation the new discipline he was about to develop ought to employ. He had opted in favour of what he called a ‘physician’s outlook’:

> The Method I take to do this, is not yet very usual; . . . I have taken the course (as a Specimen of the Political Arithmetick I have long aimed at) to express my self in Terms of *Number*, *Weight* or *Measure*; to use only Arguments of Sense, and to consider only such Causes, as have visible foundations in Nature; leaving those that depend upon the mutable Minds, Opinions, Appetites and Passions of particular Men, to the Consideration of others . . . (Petty, 1662, p. 244; emphasis in the original)

Political economy was to be as *objectivist* as possible. As his paper of 1928 shows, Leontief advocated a very similar point of view.

It will not have escaped the reader’s attention that Petty emphasizes that all causes which we nowadays summarize under the heading of preferences or subjective factors have no role to play in political economy. He does not say that these factors do not exist, or that they are unimportant. He only insists that they are not the object of ‘political arithmetick’.

The new theory was developed by scholars such as Richard Cantillon, François Quesnay, Adam Smith, David Ricardo and Robert Torrens, to mention but some of the most influential ones. The most important features of what Leontief called the ‘classical theory of interdependence’ are the following.

1. Production consists essentially in a transformation of matter and energy into other forms of matter and energy; this process is time consuming and subject to the laws of science (especially physics, chemistry and biology).
2. Production involves destruction, and the real cost of a commodity consists first and foremost of the amounts of commodities necessarily destroyed in the course of its production. This leads to the concept of ‘physical real cost’.
3. There is no such thing as production carried out by unassisted labour: it is impossible to produce something out of nothing.
4. Production is essentially a circular flow: commodities are produced by (means of) commodities.
5. Human production typically generates a social surplus. The surplus refers to those quantities of the different commodities that are left over after the necessary means of production are used up and the means of subsistence in the support of labourers have been deducted from the gross outputs produced during a year.

Features 1 and 3 are well expressed by James Mill’s famous dictum that man cannot create matter, man can only decompose and recompose it, change its form and move it (Mill, 1826, p. 107). Without too much of an exaggeration one can say that the classical economists tried to respect what nowadays are known as the laws of thermodynamics.

A particularly clear, and in fact astounding, expression of the physical real cost approach to the problem of value, feature 2, has been put forward by the self-same James Mill, Ricardo’s elderly friend. Mill insisted:

> *The agents of production are the commodities themselves*. . . . They are the food of the labourer, the tools and machinery with which he works, and the raw materials which he works upon. (Mill, 1826, p. 165; emphasis added)

The commodities are the agents! It is the food etc that enables the worker to perform his or her tasks in a similar way as the fodder enables the horse, and the fuel the machine, to operate. The contrast to the concept of ‘agent’ in contemporary mainstream economics could hardly be greater! While the classical authors were bound to weaken this bold view somewhat in the case in which workers receive wages that exceed mere subsistence, it forms the rock-bottom of their analyses.

The idea expressed in feature 4 can be traced back to William Petty and Richard Cantillon and was most effectively expressed by François Quesnay (1759) in his *Tableau économique*. The different parts of an economy are typically interdependent and form a connected system of production. Therefore, a general analysis is needed. A rather sophisticated analysis of general economic interdependence was in fact for the first time provided by the ‘physiocrat’ Quesnay. It is not for nothing that Leontief associated his own work closely with the *Tableau économique*.[6]

[6] See Leontief (1936, [1941]1951, 1966). The parallel with Piero Sraffa, who related his analysis also to the *Tableau économique* (see Kurz, 2006, and Kurz & Salvadori, 2006), is close at hand.

Feature 5 raises a number of important issues and is the source of difficult conceptual and analytical problems that constituted, and still constitute, formidable stumbling blocks to economists. First, in systems characterized by the conservation of matter and energy the question is, in what sense is it possible to speak of a surplus? Apparently, it is the production of things that are useful to humans that matters. How does this process of wealth creation affect the environment? Using Mill's above concept of production, growing economies are involved in continuously increasing the quantity of matter they decompose and recompose and the amount of energy they put to work. Such processes can sensibly be described only as joint production processes. Each process is the source of many effects, only some of which we take into account. We distinguish between 'goods' and 'bads', and it is well known that the convenient assumption of 'free disposal' cannot be sustained. The disposal of many bads is a highly costly activity—think of nuclear waste and its removal. Second, how is the surplus distributed amongst different claimants, and what are the implications of different distributions with respect to (a) the properties of the given system of production in use, and (b) the forces at work that transform the system over time? The former problem leads directly to the classical analysis of value and income distribution, the latter to the analysis of capital accumulation, economic development and growth.

This rich picture of the economic system elaborated by the classical economists and those working in their tradition allows one to adopt a wider perspective from which one may assess input–output analysis, its achievements and its yet to be explored potential. Before touching upon these aspects we show that Leontief's 1928 essay expresses with great clarity the classical perspective sketched above. This is hardly surprising, given his early training as an economist and his collaboration with scholars like Ladislaus von Bortkiewicz in Berlin and Adolph Löwe and Alfred Kähler in Kiel.

4. Leontief's Essay of 1928

Leontief premises his analysis on the conviction that economics should start from 'the ground of what is objectively given' (Leontief, 1928, p. 583). Economic concepts that do not refer to magnitudes that can, at least in principle, be observed and measured are said to be meaningless and potentially misleading. He explicitly adopts a 'naturalistic' or 'material' perspective (p. 622). The starting point of marginalism, *homo oeconomicus*, he considers inappropriate because it gives too much room to imagination and too little to facts (pp. 619–620). The starting point should rather be the concept of circular flow, which expresses one of the fundamental objective features of economic life. We may paraphrase Leontief's point of view in terms of a remark made by the character Lord Henry Wotton in Oscar Wilde's *The Picture of Dorian Gray*:

> The true mystery of the world is the visible, not the invisible. (Wilde, ([1891] 1994), p. 30)

So what is visible according to Leontief and how does it help us to see through the mystery of the world and unravel what is invisible?

Leontief illustrates his basic ideas in terms of a two-sector input–output system. He assumes single production and constant returns to scale throughout. Much of his analysis focuses on the case of a stationary system. He tabulates the 'relations of production' in the following way (Leontief, 1928, p. 598):

$$aA + bB \rightarrow A$$

$$(1 - a)A + (1 - b)B \rightarrow B,$$

where A and B give the total quantities produced of two, possibly composite, commodities, and a and b [$(1 - a)$ and $(1 - b)$] give the shares of those commodities used up as means of production and means of subsistence in the first (second) sector. Each product is needed in the production of itself and in that of the other product. The input of the product in its own production may successively be replaced by the input of the other product, a procedure known as the 'reduction to dated input quantities'. Because of the circular character of production, Leontief insists that 'a complete elimination of a factor of production from the given system is in principle impossible.' He adds: 'Of course, the size of the "capital factor" can be reduced to any chosen level by referring back to even earlier periods of production' (p. 622). This reduction, he stresses, has nothing to do with a historical regress (p. 596, fn. 6).

Most important, Leontief leaves no doubt that the physical scheme of production holds the key to the mystery of what governs the exchange relationships between commodities in a capitalist economy. In fact, he insists that the exchange relationships, or relative values, can be 'deduced from all the relationships ... analysed so far' (p. 598). However, in order to be able to do this, one more piece of information is needed. It concerns the rule according to which the surplus is distributed. Leontief writes: 'In the general circular flow scheme, income from ownership is of course considered alongside other cost items ... It is the task of the theory of interest to investigate these fundamental relationships [between relative values and income distribution]' (p. 600). In conditions of free competition, that is, the absence of barriers to entry in and exit from the various spheres of production, the surplus is distributed in terms of a uniform rate of return on the value of capital invested across all industries. The corresponding price equations bring together the above physical scheme and the rule of distribution.

Leontief goes a step further and asks himself what are the implications of a change in relative prices for the distribution of income and for the advances, or 'capital', in each sector and in the economic system as a whole. 'One may', he writes, 'vary at will the exchange proportions and consequently the distribution relationships of the goods without affecting the circular flow of the economy in any way' (pp. 598–599). In other words, the same physical input–output schema can support different price systems reflecting different distributions of income. Leontief relates this finding to the classical economists who are explicitly said to have advocated a 'surplus theory' of value and distribution (p. 619). Hence, the exchange ratios of goods reflect not only 'natural', that is, essentially technological, factors, but also 'social causes'. 'But this', Leontief concludes, 'is the "law of value" of the so-called objective value theory' (p. 601).

These are remarkable propositions. They show that the young Leontief was possessed of a deep understanding of the classical economists' approach to the problem of value and distribution that was far superior to that of most of his contemporaries. As Neri Salvadori and I have shown in a recent paper (Kurz & Salvadori, 2006), Leontief had independently arrived at a view that is very similar to the one Piero Sraffa elaborated at around the same time. In particular, Leontief had understood that the classical approach provided a coherent explanation of value based on material magnitudes. It constituted an analysis that was fundamentally different from the marginalist one and avoided the concepts of demand and supply functions which, Leontief emphasized, have no objective contents and to which nothing corresponds in the real world.

In his essay, Leontief also discusses briefly the problem of technical change. This problem and its various aspects concerned him throughout his life. He was especially interested in

(a) the implications of technical change for the volume and composition of employment (see, in particular, Leontief & Duchin, 1986); and
(b) the question of which technical inventions will become innovations or, in terms of the title of a paper he published in 1985, 'The choice of technology' (Leontief, 1985).[7]

It is especially this latter paper that takes up once again the classical thread of the argument.

In the following Section we draw out, in some greater detail, the explanatory power of the 'classical' approach advocated by Leontief with respect to a given system of production. In the subsequent Section we then deal with Leontief's analysis of the choice of technology (or technique) and thus changes in the system of production.

5. The System of Production: A Determinant of Relative Prices and Distribution

The information about the system of production in use and real wages (i.e. the quantities of commodities in the support of workers) is all that is needed in order to determine directly the system of relative prices and the competitive rate of profits. In order to show this, we may start from James Mill's case of an economy with three kinds of commodities, tools (*t*), raw materials (*m*), and the food of the labourer (*f*). Keeping close to Leontief's above tabulation, production in the three industries may then be depicted by the following system of

[7]Following the convention adopted in Kurz & Salvadori (1995), we prefer to talk of a choice of technique, because we define 'technology' as the set of all available methods of production at a given moment of time, only some of which will typically be chosen, that is, operated.

quantities

$$T_t \oplus M_t \oplus F_t \rightarrow T$$
$$T_m \oplus M_m \oplus F_m \rightarrow M$$
$$T_f \oplus M_f \oplus F_f \rightarrow F,$$

where T_i, M_i and F_i designate the inputs of the three commodities (employed as means of production and means of subsistence) in industry i ($i = t, m, f$), and T, M and F total outputs in the three industries. The symbol $\oplus$ (which replaces Leontief's and Sraffa's potentially misleading $+$) indicates that all inputs on the left-hand side of the arrow (which represents production) are required to generate the output on the right-hand side. Adopting the terminology of the classical authors, we may speak of 'the methods of production and productive consumption' (Sraffa, 1960, p. 3). In the hypothetical case in which the economy is just viable we have

$$T = \Sigma_i T_i, M = \Sigma_i M_i, \text{ and } F = \Sigma_i F_i.$$

From this schema we may directly derive the corresponding system of 'absolute' or 'natural' values (Ricardo), which expresses the idea of physical real cost-based values in an unadulterated way. Denoting the value of one unit of commodity i by p_i ($i = t, m, f$), we have

$$T_t p_t + M_t p_m + F_t p_f = T p_t$$
$$T_m p_t + M_m p_m + F_m p_f = M p_m$$
$$T_f p_t + M_f p_m + F_f p_f = F p_f.$$

Only two of the three equations are independent of one another. Fixing a standard of value whose price is *ex definitione* equal to unity, provides an additional equation without adding a further unknown and allows one to solve for the remaining dependent variables.

A numerical example (taken from Sraffa's hitherto unpublished papers) illustrates the finding that the given socio-technical relations rigidly fix relative values:

Values

$$2p_t + 15p_m + 20p_f = 17p_t \quad p_t = 3p_m$$
$$5p_t + 7p_m + 4p_f = 28p_m \quad p_m = \tfrac{2}{3}p_f$$
$$10p_t + 6p_m + 11p_f = 35p_f \quad p_f = \tfrac{1}{2}p_t.$$

These values depend exclusively on necessities of production. They are the only ones that allow the restoration of the initial distribution of resources. As Leontief indicated, echoing Adam Smith, the value of any one commodity may be 'reduced' to a certain amount of another commodity needed directly or indirectly in its production. For example, one might reduce one unit of commodity t to an amount needed of commodity m. Hence, one might say that each of the three commodities could serve as a 'common measure' and that, for example, commodities t

and f exchange for one another in the proportion 1:2, because commodity t 'contains' or 'embodies' twice as much of commodity m as commodity f.

We now turn to a system with a surplus and given real wages advanced at the beginning of the production period. In conditions of free competition the surplus will be distributed in terms of a uniform rate of profits on the 'capitals' advanced in the different industries. Obviously, we now have

$$T \geq \Sigma_i T_i, M \geq \Sigma_i M_i, \text{ and } F \geq \Sigma_i F_i,$$

where with regard to at least one commodity the strict inequality sign applies. The case of a uniform rate of physical surplus across all commodities contemplated by David Ricardo and Robert Torrens, and more than a century later by John von Neumann (1945),

$$\frac{T - \Sigma_i T_i}{\Sigma_i T_i} = \frac{M - \Sigma_i M_i}{\Sigma_i M_i} = \frac{F - \Sigma_i F_i}{\Sigma_i F_i} = r,$$

denotes a very special constellation in which the general rate of profits, r, equals the uniform material rate of produce. Here we see the rate of profits in the conditions of production and in the commodities themselves, as having nothing to do with their values. In general, the rates of physical surplus will be different for different commodities. (Some of these rates may even be negative.)

Unequal rates of commodity surplus do not by themselves imply unequal rates of profit across industries. In conditions of free competition the social surplus is divided in such a way between the different employments of capital that a uniform rate of profits obtains. This is reflected by the following system of price equations:

$$(T_t p_t + M_t p_m + F_t p_f)(1 + r) = T p_t$$

$$(T_m p_t + M_m p_m + F_m p_f)(1 + r) = M p_m$$

$$(T_f p_t + M_f p_m + F_f p_f)(1 + r) = F p_f.$$

Flukes apart, these three equations are independent of one another. Fixing a standard of value provides a fourth equation and no extra unknown, so that the system of equations can be solved for the dependent variables: the general rate of profits and prices. Apparently, the capital values of each industry and of the economy as a whole can be determined only simultaneously with the rate of profits. This has an important implication: it does away with any concept of 'capital' as a quantity that can be ascertained independently of relative prices and thus of income distribution.

So far we have assumed that real wages are given in kind at some level of subsistence. But wages in advanced economies are typically higher than mere sustenance of labourers. Hence, a new wage concept is needed. This case had already been studied by Ricardo and had made him establish the inverse relationship between the real wage rate, or the share of wages in the national product, and the rate of profits (or 'wage curve'): 'The greater the *portion of the result of labour* that is given to the labourer, the smaller must be the *rate* of profits, and vice versa' (*Works*, Vol. VIII, p. 194; emphases added). (As we will see in the following section, Leontief adopted this important concept in his discussion of the choice of technique problem.) When workers participate in the sharing out of the surplus product, the original idea of wages being entirely paid out of social capital, i.e. advanced at the beginning of the production period, is difficult to sustain. We immediately shift to the alternative view, as it is generally adopted today, and treat wages as a whole as paid out of the product, i.e. *post factum*, and in proportion to the amounts of labour employed in the three industries, L_t, L_m and L_f. Following the classical economists, differences in the quality of labour have been previously reduced to equivalent differences in quantity so that each unit of labour receives the same wage rate (see Kurz & Salvadori, 1995, Ch. 11). We may now formulate the corresponding system of production equations for the case of the three kinds of commodities mentioned by Mill, where now the quantities T_i, M_i and F_i represent exclusively the inputs of the three commodities employed as means of production. We get

$$(T_t p_t + M_t p_m + F_t p_f)(1 + r) + L_t w = T p_t$$

$$(T_m p_t + M_m p_m + F_m p_f)(1 + r) + L_m w = M p_m$$

$$(T_f p_t + M_f p_m + F_f p_f)(1 + r) + L_f w = F p_f.$$

Fixing a standard of value and taking one of the distributive variables, w and r, as given, we can determine the remaining variables: r (or w) and the prices of the commodities in terms of the standard.

It can be shown that whereas the wage rate is, as Ricardo had maintained, necessarily a decreasing function of the rate of profits,[8] no simple rule governs the behaviour of any relative price as a function of the rate of profits: the function can alternately be increasing or decreasing, and can pass through unity a number of times (but that number is constrained by the overall number of commodities involved, in the above simple example: three). This fact is important also because the problem of the choice of technique from among several alternatives can be studied following substantially the same argument.

6. Choice of Technique and Technical Progress

We are now in a position to deal with Leontief's discussion of the 'choice of technology' (Leontief, 1985).[9] The choice of technique problem is an integral part of the process of technical change, because in order to have any economic relevance, new technical knowledge—the invention of a new product or a new process of

[8]The point applies to single product systems. When commodities are produced jointly, it need not be the case that $\mathrm{d}w/\mathrm{d}r < 0$ irrespective of the standard of value that is chosen.
[9]Leontief's article on this topic was an outgrowth of his collaboration on a huge study of the impact of automation on workers in the US (Leontief & Duchin, 1986). For an investigation of the employment effects of automation with respect to what was the Federal Republic of Germany, see Kalmbach & Kurz (1991, 1992). The dynamic input-output model used in this study avoids some of the difficulties besetting the Leontief & Duchin model.

production—must actually be adopted and used; that is, it must become an innovation. Whether a new technique will in fact be adopted depends on whether it can be profitably introduced. If it is successful and gradually spreads through the economic system, it may affect not only the sector to which it directly belongs, but the system as a whole.[10] For example, if technical change concerns a product, such as electricity, that can safely be assumed to enter directly or indirectly into every product, then the entire economy will have to change in one way or another: material and energy streams, labour employment, relative prices and income distribution are all bound to change. As Leontief (1985, p. 25) puts it succinctly: 'The ripple of a new technology throughout the economy leads to effects that are not predictable by examining each industry in isolation. Every decision to introduce technology could be based on data available to all.'

In determining prices in the economic system, Leontief (1985, pp. 28–29) adopts precisely the classical approach: 'Given such technological information one can set up a system of equations from which the prices of all inputs and outputs within the economy can be calculated.' And: 'Under a fixed technology there is only one corresponding level of real wages for any given rate of return' (p. 29). The relationship between the two distributive variables is inverse, which expresses the fact that 'the interests of investors and wage earners collide' (Leontief, 1985, p. 29). Finally, '[t]he reciprocal relation between real wages and rate of return for a given technology can be interpreted as a measure of the productivity of the economy based on that technology' (Leontief, 1985, p. 29). A new technique, Leontief emphasizes, implies 'setting up a new system of equations' (Leontief, 1985, p. 29). This is fully in line with Leontief's 1928 paper, and it is also fully in line with Piero Sraffa's resumption of the classical standpoint from Adam Smith to David Ricardo in *Production of Commodities by Means of Commodities*.

Leontief reports the following important and interrelated results.[11]

1. Technical change typically changes the location and shape of the relationship between the rate of profits and real wages, or the *w-r* relationship, also known as the wage curve. Different forms of technical change involve different shifts of the wage curve.
2. Some newly available methods of production might not be introduced, because at the given income distribution and the associated system of prices associated with the system of production in place (or what Leontief calls the 'current economic climate', p. 30), it would not be profitable to do so, whereas at some other distribution and prices, it could be profitable. Technically speaking, the *w-r* relationships associated with the two systems of production (or techniques) may intersect; they may actually intersect more than once, a case Leontief does not discuss. Hence, the choice of technique depends not only on the

[10]Again, we abstract from the empirically important phenomenon of joint production, which raises formidable problems in economic theory and in applied work. One of its implications is that processes of production and thus the products they generate cannot easily be classified into neatly defined sectors.

[11]The following argument draws partly on Kurz & Salvadori (2008).

technological features of the various methods of production, old and new, but also on the level of the rate of return (or, alternatively, the level of real wages).
3. If there are new methods of production available for several commodities simultaneously, then the question whether one particular method will be adopted cannot generally be decided by looking only at the characteristics of this method. All available options must be taken into consideration.
4. This implies that a global rather than a local perspective on the problem at hand is required. A partial analysis that focuses attention on a single sector only, may be utterly misleading, because it might predict the adoption of a technique which is actually dominated by a superior one, or it might predict that a method will not be adopted, although it actually will (see the examples provided in Kurz, 2008). (Whether the needed general analysis is possible, depends of course on the availability of data.)
5. Looking carefully at the succession of wage curves reflecting technical change in Leontief's diagrams shows that in all three of them he assumes that technical change increases the maximum level of real wages, and decreases the maximum rate of profits. Technical change is thus taken to increase labour productivity and decrease capital productivity. This is interesting, because implicitly it refers to a form of technical change that was first discussed by David Ricardo in the chapter 'On machinery' in the third edition of his *Principles*, published in 1821, and then by Karl Marx in terms of a rising overall 'organic composition of capital'.[12]

Leontief's reasoning is based on the idea that the choice of technique is 'an elimination contest between two [or several] teams: the old technology and the new [ones]' (Leontief, 1985, p. 33). Let us provide a simple formalization of this idea. Recall in this context our finding that in a system with many commodities the relative price of any commodity as a function of the rate of profits typically does not follow a simple rule: the function can alternately be increasing or decreasing, and can pass through unity several times. Suppose, for instance, that due to a technical invention commodity t could also be produced using the following method

$$T'_t \oplus M'_t \oplus F'_t \oplus L'_t \rightarrow T'.$$

Then we can add to our above system of price equations the equation

$$\left(T'_t p_t + M'_t p_m + F'_t p_f\right)(1 + r) + L'_t w = T' p'_t,$$

with the further unknown p'_t.[13] The magnitude of the ratio p'_t/p_t allows us to say

[12]For a detailed discussion of the classical economists' approach to the problem of technical change, income distribution and capital accumulation, see Kurz (2010). The type of technical change portrayed by Leontief some authors dub 'Marx-biased technical change'; see Foley & Marquetti (1999).
[13]As Leontief (1985, p. 32) stressed: 'Costing out a new technology in this way calls for solving only one equation, into which the proposed new industrial recipe ... is substituted', given the input prices of the 'old' technique.

when it is profitable to use the old method and when the new one: if p'_t/p_t is smaller than 1, the new method will be chosen by cost-minimizing producers; if it is larger than 1, the old method will be retained, whereas both methods can coexist in case $p'_t/p_t = 1$. Obviously, if the new method is chosen and replaces the old one, and if it is assumed that the general rate of profits is unchanged, then our equations in the above give way to the following equations, serving as the new system

$$\left(T'_t p'_t + M'_t p'_m + F'_t p'_f\right)(1+r) + L'_t w' = T' p'_t$$
$$\left(T_m p'_t + M_m p'_m + F_m p'_f\right)(1+r) + L_m w' = M p'_m$$
$$\left(T_f p'_t + M_f p'_m + F_f p'_f\right)(1+r) + L_f w' = F p'_f.$$

In this new system, prices and the wage are different ($p'_j \neq p_j$ and $w' \neq w$), but they are not so when $p'_t/p_t = 1$. If we were to assess the old method in terms of the prices and wage of the new system by combining the price equations of the new system and the equation

$$\left(T_t p'_t + M_t p'_m + F_t p'_f\right)(1+r) + L_t w' = T p_t,$$

we can calculate again the ratio p'_t/p_t, and the property that prices and the wage in the two systems coincide when $p'_t/p_t = 1$ is enough to prove that p'_t/p_t is larger (lower) than 1 for a given r in the new system, if and only if it is so in the old system. Hence, the comparison between the new process and the old one can be indifferently done either in terms of the prices corresponding to the old or in terms of the prices corresponding to the new system. The argument would have to be generalized to allow for durable instruments of production, mentioned by Leontief (1985, p. 30), joint production proper and scarce natural resources (see Kurz & Salvadori, 1995).

To conclude, we turn briefly to the form of technical change Leontief assumes in the three diagrams of his paper showing wage curves. It suffices to reproduce the second figure (see Figure 1).[14] It involves an increase in labour productivity, reflected by an increase in the maximum wage rate (corresponding to a zero rate of profits), and a decrease in capital productivity, reflected by a decrease in the maximum rate of return (corresponding to zero wages), which equals the output-to-capital ratio, in familiar notation: Y/K. The case under consideration mimics the shift of the wage frontier in Ricardo's chapter on machinery, in which Ricardo discusses the substitution of machine power for labour (and animal) power, which increases labour productivity and at the same time reduces capital productivity. In Figure 2 (the axes are now reversed) T represents

[14] A slip in Leontief's argument ought to be pointed out. He seems to think that the relevant wage frontier after the innovation is what he calls 'New Technology'. However, this is not so. What matters is the outer envelope of all wage curves, which includes the outermost piece of the 'myopic view' curve on the bottom at the right-hand side of the diagram.

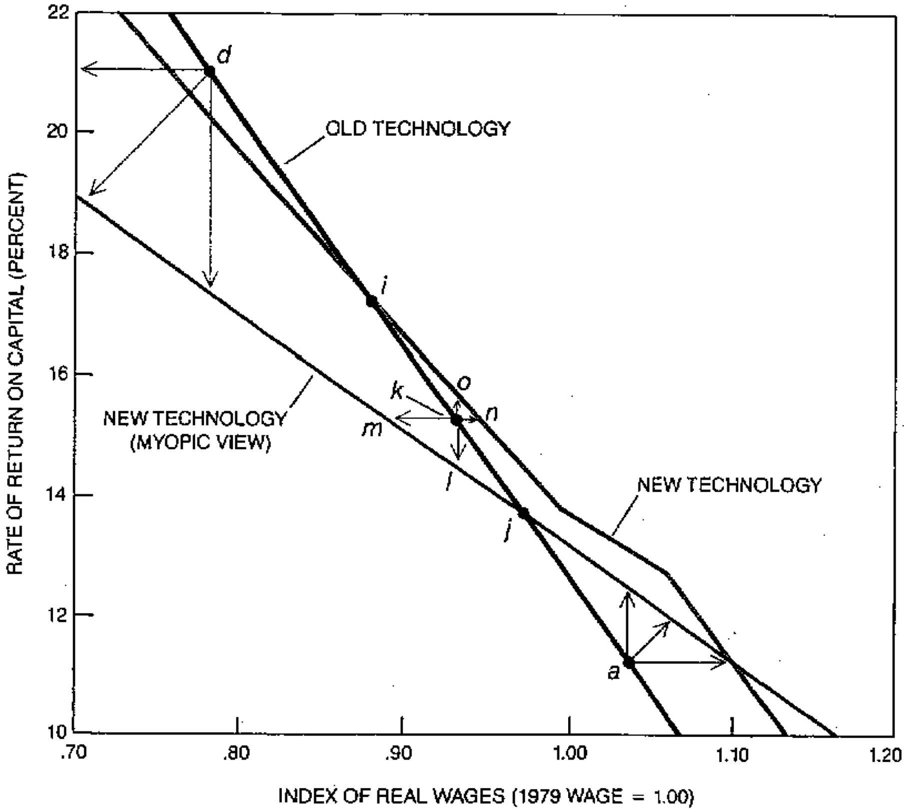

Figure 1. Wage curves. Source: Leontief, 1985, p. 30.

the old technique and M the new one. The switchpoint between the two techniques is given by w^* and r^*. At levels of the real wage rate below w^*, the new technique would not be introduced despite the fact that it would bring about a remarkable increase in labour productivity. For $w = w_0$, technique M would replace technique T, and for a given and constant real wage rate it would entail an increase in profitability from r_T to r_M. Alternatively, with a given and roughly constant general rate of profits, the real wage rate would be bound to rise.

According to Foley & Marquetti (1999), who however derive their findings from a macro and not an input–output analysis, this form of technical progress has been dominant in recent decades in all developed economies. For a discussion of the problem within a multisector framework using input–output tables from four major OECD countries between 1970 and 2000, see Degasperi & Fredholm (2009).[15]

[15]In the above we have assumed for simplicity that all capital is circulating capital. Matters are more complicated when fixed capital is present. While the circulating part of the capital goods advanced in production contributes entirely and exclusively to the output

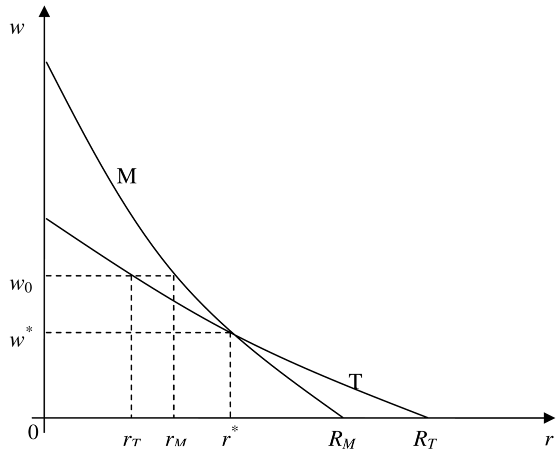

Figure 2. Ricardo's case of gross-produce reducing improved machinery

7. Concluding Remarks

This paper shows that in his 1928 paper on the economy as a circular flow as well as in his 1985 paper on technical progress and the choice of technique, Leontief adopted a strictly 'classical' point of view. In fact, Leontief can be said to have elaborated the classical approach in several directions and to have shown how it can be used in empirical studies. In particular, Leontief was fully aware of the fact that the 'value added' in each industry as well as in the economic system as a whole can be endogenously determined in terms of the system of production in use and the rule fixing the sharing out of the social product between the different claimants, typically workers and capital owners. There is no need, and indeed no possibility, to start from given 'value added coefficients' in Leontief's 'value-added price equations' (Leontief, [1941]1951). The difficulty with this latter procedure is that the magnitudes of value added per unit of output in the different industries can only be known when distribution and prices are known. Therefore, one might say that Leontief's price determination in terms of given value-added coefficients involves a regression compared with his earlier and his later analysis.[16] The input–output model, if combined with some extra hypotheses, is a more powerful analytical tool than is widely acknowledged. Developing its potentialities, I surmise, should be high on the agenda of input–output theorists

generated, that is, 'disappears' from the scene, so to speak, the fixed part of it contributes to a sequence of outputs over time; that is, after a single round of production goods which constitute fixed capital remain in existence, older but still useful. For a discussion of fixed capital within the framework of universal joint production, see Kurz & Salvadori (1995, Chapters 7 and 9).

[16]While analytically Leontief's procedure involved a step backward, one has to acknowledge that in so far as the empirical investigation of practical problems is concerned he faced the constraint that the data available to him were typically in monetary terms.

and applied economists. As Leontief's own work shows, the model allows for a fruitful probing into the intricate problem of technical change and employment. In this context the constraint binding changes in the distributive variables, the real wage rate (or the share of wages) and the rate of return on capital, performs a useful role in distinguishing different forms of technical progress.

There are still many aspects of a real economy that deserve closer scrutiny. One such aspect is the problem of fixed capital. Its cavalier treatment in several studies is, of course, very often due to the fact that reliable data are missing, which would allow the use of a more refined approach to the problem of durable instruments of production. A simplified version of the joint-products approach to durable instruments of production, as was suggested by Robert Torrens and then used by John von Neumann and Piero Sraffa, could perform a useful role in applied work. On the simplifying assumption of constant efficiency of machines etc and given their economic lifetime, things are quite straightforward and do not cause difficulties. The annuity of a machine as well as the value of a stock of machines that is evenly distributed across all vintages depends on income distribution. The larger is the rate of profits, the larger is the value of such a stock relative to the price of a new item of machines. Because of the dependency of the value magnitudes under consideration on the rate of profits, several of the typical assumptions employed when dealing with fixed capital cannot be sustained. In particular, the contribution of fixed capital to value generation cannot be taken to be knowable independently of the rate of profits, and such depreciation concepts as 'depreciation by evaporation' or 'depreciation by radioactive decay' turn out to be untenable.

Sooner rather than later, the problem of joint production has to be given proper attention. With 'goods' and 'bads' produced jointly, and with the need to dispose of the bads in terms of costly disposal processes, the problem of 'negative prices' makes an appearance. Environmental problems, I surmise, have to be tackled in terms of a joint-products approach.

A serious limitation of many input–output studies of technical change (including our analysis in the above) is that new methods of production typically require entirely new means of production and also new kinds of labour, yet little attention is paid to this fact. Process and product inventions go hand in hand and presuppose the availability of new types of labour (see again Kurz, 2008). With the introduction and gradual generalization of new products and means of production, some old products may be eliminated. This however means that the dimensions of input–output tables are bound to change, both quantitatively and qualitatively. This problem is well known and raises huge difficulties, which are beyond the scope of this paper.

The above discussion should make clear why input–output analysts have good reasons to embark on the classical approach to economic problems, as did Leontief in his maiden paper and then in a number of other contributions. The classical approach is highly fertile and versatile and allows one to tackle a number of important economic problems in a coherent way, including the problems of employment, technical change and the environment. An important precondition of its success is, of course, the availability of reliable data. Please do not hesitate to kiss Sleeping Beauty.

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