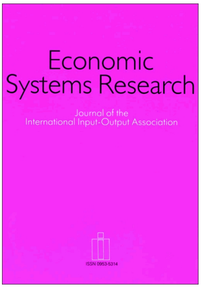

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Leontief's Great Leap Forward: Beyond Quesnay, Marx and von Bortkiewicz

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ABSTRACT *Wassily Leontief's input–output analysis is often interpreted simply as a logical next step in the chain of ideas from Quesnay to Marx to von Bortkiewicz, the last of these having been Leontief's thesis adviser in Berlin. Here, it is shown that input–output is far more than that. Unlike any predecessor, it is a flexible model with widely varied applications that permits direct empirical evaluation. This is illustrated by application to net energy calculations, showing that the normal evaluation methods that ignore input–output considerations probably overestimate by 20 to 60% the net energy yield of projects designed to save energy.*

1. Introduction

It has become customary, indeed almost obligatory, when speaking of Wassily Leontief's contribution to our discipline to trace a direct lineage from Quesnay's zigzag table to the invention of input–output. Indeed, I must confess myself guilty of this sin. The point of this paper is to confirm that it is, indeed, a sinful denigration of Professor Leontief's accomplishment, because it implies that his contribution is just an incremental addition to the earlier writings rather than being, as I will argue, a revolutionary departure. It provides us with a new and powerful tool adaptable to empirical investigation and analysis of a variety of applied issues, giving us a means of going beyond anything the supposed predecessors might have imagined their work to permit.

In outline, the usual story is that the *Tableau Économique* is the first general equilibrium model in the literature and that, minor figures such as Canard and Isnard apart, Marx was the direct successor of the physiocrats and among the first subsequent analysts in the arena. After Marx left his transformation problem unsolved, von Bortkiewicz took up the implied challenge and built upon the rudimentary general equilibrium model (the 'simple reproduction model') to provide a viable solution to the transformation problem, one that is still widely relied upon. Then, when Leontief arrived in Berlin as a student, von Bortkiewicz was assigned to him as dissertation adviser, thereby completing the chain that carried the interdependence analysis from Quesnay to Leontief.

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One must always approach such tales with some degree of caution. Like the rest of us, those who specialize in the history of economic ideas have a favourite pastime: finding predecessors. This is a commendable activity, but it has its perils and temptations. It is all too easy to find an obscure but early piece in which some relative of the word 'interdependence' makes an appearance (as, perhaps, in John Donne's 'No man is an island') and to conclude from this that the item represents an early incursion into general equilibrium analysis. But Donne surely cannot reasonably be credited as an early anticipator of either Walras or Leontief and, while the case for Quesnay, Marx and von Bortkiewicz is patently somewhat stronger, I will argue that their association with Leontief's contribution is, at best, misleading. For, as will be demonstrated here, the Leontief contribution is indeed a giant leap forward, and not a mere extension of the work of those claimed as his predecessors. Leontief's contribution is revolutionary, not incremental. It transforms closely targeted abstractions of doubtful applicability into an operational, widely employable analytic instrument.

To demonstrate my contention, this paper will, in turn, briefly review the pertinent contributions of the other authors, beginning with Quesnay.[1]

2. On the *Tableau*, its Structure and Purposes

François Quesnay provides a fascinating story. Surgeon and physician to Madame de Pompadour and, later, to Louis XV, he was the author of numerous writings on medical subjects. During Adam Smith's stay in Paris the two spent some time together, and Quesnay was even called out of retirement from his medical practice by Smith, when the latter's pupil, the Duke of Buccleugh, fell ill (Adam Smith's letter to Charles Townshend, 26 August 1766, as reproduced in Rae, 1895, p. 222). At the age of 63, his interest in political economy was reportedly first aroused in a discussion in an *entresol* at Versailles. Together with the Marquis de Mirabeau, Pierre Samuel du Pont de Nemours, and others he formed a group, the *Économistes*, since referred to as the Physiocrats, which controlled several journals and remained influential until about 1770.

The *Tableau* apparently had first appeared towards the end of the 1750s in a small volume distributed by Quesnay to a very few people. Although this became known as the 'first edition', it transpires that there had been two earlier versions, so that it has since been relabelled the 'third edition'. This last version itself has a curious subsequent history. It is apparently this document that was described by Du Pont in his history of the beginnings of the physiocratic movement. But then it disappeared, only to be found in 1905 and described superficially by a man named Schelle who announced that he was not at liberty to show it to anyone or even to reveal the source from which it had been obtained. Then it vanished again, until it was rediscovered in 1965 by Marguerite Kuczynski, who guessed correctly that it must exist among the Du Pont family papers in Wilmington, Delaware. She and Ronald Meek subsequently prepared a fine scholarly volume that includes the three editions of the tableau.[2]

All this is provided only for the reader's interest. For my purposes here, it is, of course, beside the point. The point, rather, resides in the substance of the *Tableau*. Figure 1 is a stylized version of part of its noted 'zigzag table', taken from one of the two extant versions of the 'second edition'.

To understand its purpose, we need merely recall a basic tenet of physiocratic doctrine, the view that agriculture is *the* productive economic activity, and that

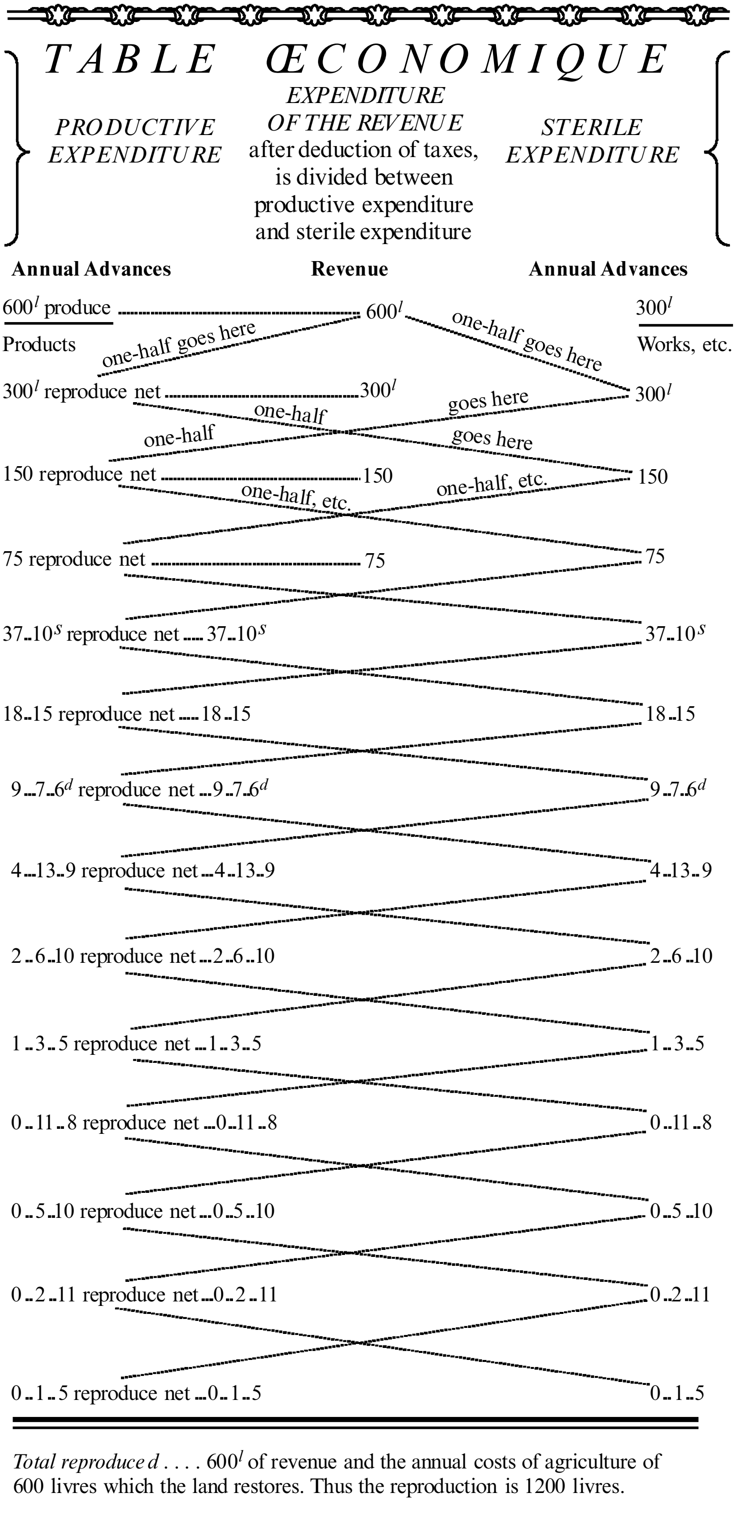

Figure 1. Part of the 'zigzag table'.
Source: Kuczynski & Meek (1972).

manufacturing activity is 'sterile', yielding output worth no more than the agricultural inputs that go into it. The purpose of the table is to show how this works itself out, with investment in agriculture producing a surplus that is divided between landlords and the artisans who carry out the sterile activities. The zigzag represents a repeated set of flows of resources among the three groups, with landlords initially investing 600 livres, divided equally between agriculture and manufacturing. Agricultural activity yields a 100% surplus in each round of activity, so that the initial 300-livre investment there brings a surplus of 300 to the landlord. Of the remaining 300 livres of agricultural output, half is retained for direct consumption by the farm cultivators, and half is used by them to make purchases from the artisans. Similarly, the artisans use the initial 300 investment to produce 300 in output (but with zero surplus), consuming half themselves, and using the remainder to buy agricultural products. Thus, at the end of the first round, each of the two sectors has received 150 livres from the other, which it invests in its economic activities once more, this time starting with an outlay half as large as it did in the first round. This is repeated over and over, each stage involving half the volume of resources of its predecessor. This, in sum, is what goes on in the zigzag table.

The contribution is, of course, substantial. It is an integrated picture of the interconnections within the two macrosectors of the economy that were the foci of physiocratic thought. It displays the workings of the interconnections and brings them all together into a coherent whole. It can even be said to provide a prototype for convergent multiplier series. For us, however, the significant issue is what it is *not*. It is not a flexible analytic tool. It is difficult to think, for example, of any current policy problem on which the zigzag can cast any light. It does not lend itself to empirical work except, perhaps, to statistical measurement of its aggregate intersectoral flows, which would seem to lead no further In sum, it is far short of the flexible analytical tool that input–output analysis provides.[3]

3. Marx's Physiocratic Inheritance

Although the work of the physiocrats was discussed by the classical economists, notably by Adam Smith, it is Marx who drew attention to the *Tableau*. He was enthusiastic about its contribution, even describing it as 'incontestably the most brilliant idea of which political economy had hitherto been guilty' (Marx, 1963, Vol. I, Chapter 6, last page). Let us see why Marx considered it important, and what the analysis became in his hands.

There are three clear reasons for Marx to impute great value to Quesnay's model. First, and most obvious, the model depicts the interworkings of the different parts of the economy, explicitly tracing through the paths of the circular flow:

> ...it was an attempt to portray the whole production process of capital as a *process of reproduction*,... the relation between reproductive consumption and final consumption; and to include in the circulation of capital the circulation between consumers and producers... and finally to present the circulation between the two great divisions of productive labor—raw material production and manufacture—as phases of this reproductive process. (Marx, 1963, Vol. I, p. 344)

Secondly, Marx was attracted to the zigzag table because it provides an early theory in which *surplus* plays a central role, much like the surplus value in Marxian analysis. Of course, in the earlier model it was the land, rather than labour, that produced the surplus, but Marx nevertheless saw it as a clear example of an explicit theory of surplus value.

However, there was a third feature of the physiocratic analysis on which Marx focused, consistently using Adam Smith as his bad example, who is shown up by the contrast with Quesnay. This occurs in his letter to Engels of 6 July 1863 (four years before publication of *Capital*), in the discussion of the *Tableau* in Volume II of *Capital* (Marx, 1909, Chapter 19, esp. pp. 360 ff.) and in *Theories of Surplus Value* (Marx, 1963). To quote from the letter:

> ... If you find it possible in this heat, look with some care at the enclosed *Economic Table* which I substitute for Quesnay's Table, and tell me of any objections you may have. It embraces the whole process of reproduction.
>
> You know that according to Adam Smith the 'natural' or 'necessary price' is composed of wages, profit (interest), rent—and is thus entirely resolved into revenue. This nonsense was taken over by Ricardo, although he excludes rent, as merely accidental, from the catalogue. Nearly all economists have accepted this from Smith and those who combat it commit some other imbecility.
>
> Smith himself is conscious of the absurdity of resolving the *total product* for society *merely into revenue* ... while in *every separate* branch of production he resolves price into *capital* (raw materials, machinery, etc.) and *revenue* (wages, profit, rent).

Marx then goes on to describe his own graph (Figure 2) in which he traces through the use of labour and equipment in his two economic macrosectors, Sector I, which provides consumption goods, and Sector II, which provides means of production. The issue, here, is that for Marx a basic difference of his analysis from that of 'vulgar economics' lay in the origin of the product and its value, which was later divided into the several revenue streams. Marx emphasized that Smith and the others had focused on the circulation rather than on the production side of the circular flow and then, from the outward and superficial manifestations of the latter, was led into delusions about the former. In the circulation process the economy's product was divided into wages, profit, interest and rent. But this is merely 'the form of the illusion' in which it is made to appear, merely because capital receives profit and interest and land receives rent, that the social inputs into the production of the economy include capital and inanimate land, as well as human input.

It is not my objective here to discuss this Marxian view yet again, but to make clear that it is one of the main reasons for his interest in the *Tableau*, as Marx himself makes clear by his repeated linking of the two subjects. Patently, here too, the material is a far cry from the working tool that input–output analysis provides. But there is still more to the story.

In Volume II of *Capital*, Marx moves on from the graph in his letter and the description that follows to provide his well-known static model of economic interdependence, known as the model of 'simple reproduction' (Chapter 20). That model is easily summarized in two equations, corresponding to the two 'departments' into which he divides the economy: Department I, producers' goods; and Department II, consumers' goods. I use the following notation (with all magnitudes measured in terms of Marxian *values*):

C_j = constant capital consumed in sector j, consisting of inputs other than labour which, as we know, is assumed to yield no surplus value

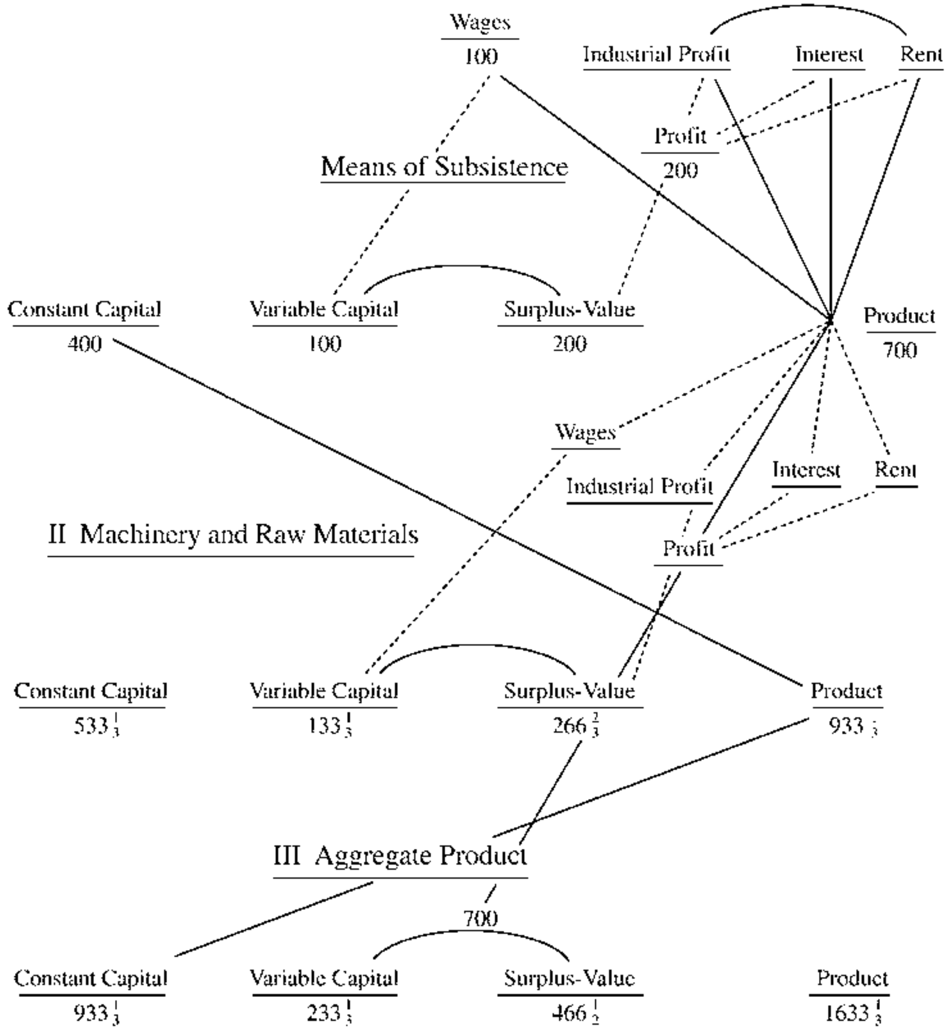

Figure 2. Marx's graph.

Source: Marx & Engels (1955) (table attached by Marx to his letter of 6 July 1863).

V_j = the variable capital (the value of the labour power) invested in j, which does yield surplus value, and
$S_j = sV_j$ = surplus value obtained from sector j. Then we have the equations

$$C_1 + V_1 + S_1 = C_1 + C_2 \tag{1}$$

$$C_2 + V_2 + S_2 = V_1 + V_2 + S_1 + S_2 \tag{2}$$

where the first equation tells us that all of the producers' goods used in the two sectors, $C_1 + C_2$, that is, the total product of Department I, equals all of the value invested in that department (its constant and its variable capital together) plus any surplus value. The second equation clearly has the analogous interpretation, with producers' goods replaced by consumers' goods, including both those that are consumed by workers and those that are consumed by the recipients of surplus value.

This is the formal structure of the simple reproduction model. It may be noted that after straightforward simplification, *both* equations reduce to one:

$$C_2 = V_1 + S_1 \tag{3}$$

This tells us merely that in a balanced economy the producers' goods produced by Department I for Department II must equal in value the consumers' goods that Department II produces for Department I—not a very startling conclusion.

It may appear that because of its extreme simplification this model has nowhere to go. It tells its straightforward story, but can it be used to tell us something else? We will see, next, that it can and does. It has, indeed, been used in a deservedly well-recognized application. But that application is not to some distant economic issue. Rather, it becomes the means for solving a theoretical problem left over by Marx himself, a problem that he, admittedly, was not quite able to solve.

4. von Bortkiewicz and the Earliest Resolution of the Transformation Problem

There is substantial literature on the transformation problem, and considerable controversy on the character of Marx's objective—matters that do not concern us here. Still, it is useful to recognize that the issue did entail one central matter that does not seem under dispute. In volume I of *Capital*, and elsewhere, Marx had carried out his analysis in terms of a unit he called 'value', which is equal to the labour-time contained in a product. Marx maintained that use of this unit revealed the underlying reality of the process of production and the creation of surplus value. In contrast, he held that calculation in the plainly visible pecuniary units—prices, wages, profits, interest and rent—were 'the forms of the illusion' that concealed what was really going on: 'By the transformation of values into prices of production, the basis of the determination of value is itself removed from direct observation' (Marx, 1909, Volume II, Chapter 9, p. 198). It conceals the deeper reality not only from the workers but from the capitalists themselves, and even from the vulgar economists who specialized in expounding and explaining the surface manifestations of the capital economy, not its underlying substance.

> It is an enchanted, perverted, topsy-turvy world, in which Mister Capital and Mistress Land carry on their goblin tricks as social characters and at the same time as mere things... it is... natural that the actual agents of production felt completely at home in these estranged and irrational forms of Capital-Interest, Land-Rent, Labor-Wages of Labor, for these are the forms of the illusion in which they find their daily occupation. It is also quite natural that vulgar economy, which is nothing but a didactic, more or less dogmatic translation of the ordinary conceptions of the agents of production and arranges them in a certain intelligent order, should see in this trinity, which is devoid of all internal connection, the natural and indubitable basis of its shallow assumptions of importance. This formula corresponds at the same time to the interests of the ruling classes, by proclaiming the natural necessity and eternal justification of their sources of revenue and raising them to the position of a dogma. (Marx, 1909, Vol. III, Chapter 48, pp. 966–967)

Marx's argument, moreover, was that the relation between values and prices, and that between surplus values and profits, interest and rent, was not random and fortuitous. The very capitalistic market mechanism that was encompassed in the underlying reality and that could only be analysed in value terms, at the same time automatically and systematically generated 'the forms of the illusion'—the prices, profits, interest rates and rents. Thus, it had to be possible for the latter, the illusory magnitudes, to be related *quantitatively and unambiguously* to the underlying realities, the values and surplus values. The transformation problem, then, is the problem of determining the numerical relationship that can '... for the first time ... penetrate through the outward disguise into the internal essence and the inner form of the capitalist process of production' (Marx, 1909, Vol. III, Chapter 9, p. 199). The task before Marx was to find a mathematical expression or expressions that laid out the precise relationships between the two sets of magnitudes.

Marx struggled with the calculations from the period of his work on the *Grundrisse* in 1857–8 (see, for example, Marx, 1973, Notebook IV, the chapter on Capital, pp. 434 ff.) until at least 1863. He did arrive at a solution, expressed in numerical terms, but even Marx himself recognized that it was not quite satisfactory (see Sweezy, 1949, pp. 115–116).

Marx's proposed solution is easily summed up in algebraic terms, using our earlier notation, as

$$P_k = (1 + r)(C_k + V_k) \tag{4}$$

$$r = \Sigma_k [sV_k/(C_k + V_k)] \tag{5}$$

where r is the average rate of profit, s is the rate of surplus value on variable capital (assumed constant throughout the economy) and P_k is the price of good k. This solution, then, takes the rate of profit simply to be the average of the surplus values earned per unit of constant plus variable capital in all of the economy's industries.

This attempted solution is unsatisfactory for at least two reasons. First, it is only a partial transformation, leaving quantities of capital still measured in values rather than in money terms. However, in a monetary accounting system that simply will not do, because equality of rates of profit in competitive equilibrium entails equality among industries of the ratios of money profit to *money value* of capital, not the ratio of money profits to capital measured in labour value terms. Second, as Sweezy (1949, p. 113) demonstrates, the resulting magnitudes do not even satisfy Marx's own equilibrium requirements of the simple reproduction model, as described above.

It is these equilibrium conditions, somewhat extended, that Ladislaw von Bortkiewicz, a noted statistician, used to solve the problem in 1907. von Bortkiewicz was born in St Petersburg in 1868. His family was Polish, but he spent most of his life in Germany, where he taught at the University of Berlin. He wrote a number of papers on economics, exhibiting consistent admiration for Ricardo's work.

In an article published in 1907 (see von Bortkiewicz, 1949) he pointed out the unsatisfactory state of Marx's solution of the transformation problem, and provided a viable alternative. He based it on a three-sector extension of the simple reproduction model, adding a new Department in which luxury goods are produced, with all other consumers' goods remaining in Department II. This gives us the following three equations:

$$(1 + r)(P_1 C_1 + P_2 V_1) = P_1(C_1 + C_2 + C_3) \tag{6}$$

$$(1+r)(P_1C_2+P_2V_2)=P_2(V_1+V_2+V_3) \quad (7)$$

$$(1+r)(P_1C_3+P_2V_3)=P_3(sV_1+sV_2+sV_3) \quad (8)$$

where P_k is the price per unit of the product of Department k. He supplements these three equations by taking Department III's price as numeraire, so that $P_3=1$. von Bortkiewicz then sets out to solve for r, since, once this is done, the preceding equations give us the required price figures. Writing C for $C_1+C_2+C_3$, etc, the first two equations can be written

$$P_1[(1+r)C_1-C]+P_2(1+r)V_1=0 \quad (9)$$

$$P_1(1+r)C_2+P_2[(1+r)V_2-V]=0 \quad (10)$$

For these two homogeneous linear equations in the two prices to have a non-trivial solution, the determinant of the coefficients must be zero, clearly giving us a quadratic equation in r. This equation otherwise involves only the given quantities of the constant and variable capitals. The quadratic equation can obviously be solved for the two possible values of r. That, in sum, is the von Bortkiewicz solution of the transformation problem.

For us, its important feature is its use of the Marxian simple reproduction model, whose roots, as we have seen, are to be found in the Quesnay *Tableau*. It is, clearly, an application of the model. However, it is an order of magnitude away from the type of applicability that the input–output model offers, as I will illustrate next.

5. Revolutionary Adaptability of Input–Output: Illustration in Net Energy Analysis

The discussion so far should not be misunderstood as a denigration or even criticism of the usual suspects as the predecessors of input–output analysis. It is meant only to point to the relatively specific, if not narrow, subject matter to which all of the earlier contributions apply. Their authors all had very particular topics in mind and their constructs are tailored to deal with those topics. Consequently, they provide little capacity for a venture far afield from the originally focused subject matter.

With the introduction of the input–output model, analysis of interdependence receives a new burst of freedom. It offers us a tool with a vast array of uses. Moreover, there seem to be few arenas on which the analysis can shed no light, no matter how great their difference from Leontief's initial concerns. The techniques have been applied to subjects as heterogeneous as international trade, economics of the environment and productivity issues. Just to make the point—the flexibility of the analysis, the powerful insights it offers, and its ability to solve intractable problems—I will provide a single illustration. The particular illustration is selected because it is so far away from the topics to which input–output is commonly applied, because it demonstrates that the tool is sometimes all but indispensable and, incidentally, because it is based on a study in which I was one of the participants (Baumol & Wolff, 1981).

The topic is another example of what can be described as 'well-intentioned but unthinking environmentalism'. We are all familiar with projects intended to protect the environment whose net result threatens more harm than good. For example, while recycling sometimes has great benefits, there are other cases in which it can be severely damaging because of the character of the recycling process or of the recycled materials themselves. Notable examples are the recycling of waste oil, whose processing creates emissions that can be extremely dangerous because of the character of the chemicals with which petroleum products are often treated, and the recycling of incinerator ash, for example, as road or landfill cover, because that ash itself can contain dangerous residues.

The environmental issue with which we were concerned was conservation of energy, a topic that attained considerable notoriety during the oil crisis of the 1970s. The issue elicited a variety of proposals, including, for example, increased use of solar panels, resort to renewable resources such as biomass, and the construction of subways as public transportation devices intended to reduce utilization of automobiles. As the movement grew in intensity, dispassionate observers noted that these processes all *used up* energy resources, as well as providing or saving energy. For example, the agricultural products that are used to produce biomass may be transported in trucks that use gasoline, and the process of digging subway tunnels consumes enormous amounts of power. Here are two illustrative (but not quite representative) sceptical evaluations of the sort that began to appear at the time:

> [A] house would have to operate more than forty years before the solar cells generate more electricity than was invested in their production, and we have no idea if solar cells will last that long. (Shinnar, 1976, pp. 44–45)

> ... allowing for both the energy to build vehicles and to operate them, each BART [the San Francisco subway] passenger uses 680 BTU per mile less than he would have used on the combination of cars and busses from which BART's passengers are diverted. The operating energy saving is so small ... that it will take 535 years to repay the energy invested in the system. Furthermore [taking the prospective increases in automobile efficiency into account] ... the rail system actually loses energy with every trip, and it would save energy to shut it down. (Lave, 1977, p. 5)

Granted, these quotations take positions that are more extreme than most of the evaluations offered at the time, but they do dramatize the issue.

Seeking to analyse the problems systematically, engineers invented the concept of 'net energy', in which an estimate of the energy used up by a proposed activity was subtracted from the energy it was expected to contribute. For example, one would subtract the energy needed to transport the biomass materials from the energy they could yield.

This was, arguably, a sensible way to view the matter, but it soon became clear that there was at least one major shortcoming of the procedure commonly used to carry out the calculation. There was no account taken of energy used to make the inputs needed to produce the inputs used directly in a process under study. The evaluation procedure neglected the fact that the trucks carrying the biomass themselves had to be built and used energy in the process of their construction, and that the same was true of the assembly line used to build the trucks, and so on ad infinitum. Clearly, what I am saying is that there was a Leontief process at work. In the usual notation, if we let $\mathbf{d}^{T}$ represent the vector of energy consumed per unit of output, and $\mathbf{A}$ is the Leontief matrix, then the proper measure of energy consumed is

$$\mathbf{d}^{\mathrm{T}} + \mathbf{d}^{\mathrm{T}}\mathbf{A} + \mathbf{d}^{\mathrm{T}}\mathbf{A}^2 + \ldots + \mathbf{d}^{\mathrm{T}}\mathbf{A}^n + \ldots$$

But most of the engineers carrying out the net energy studies were considering only $\mathbf{d}^{\mathrm{T}}$ as the measure of energy use. Some studies were more sophisticated and used $\mathbf{d}^{\mathrm{T}} + \mathbf{d}^{\mathrm{T}}\mathbf{A}$ as their energy consumption measure. A very few studies even subtracted $\mathbf{d}^{\mathrm{T}}\mathbf{A}^2$, but we could find no examples of any that had gone beyond this, thereby in effect assuming that $\mathbf{d}^{\mathrm{T}}\mathbf{A}^3 + \mathbf{d}^{\mathrm{T}}\mathbf{A}^4 \ldots = 0$.

What Wolff and I did at this point should by now be obvious. We carried out a full input–output calculation, using the available input–output data on the US economy. The conclusions were clear, and rather startling. We found that the usual approach that took into account only the energy of the directly-used inputs on average overlooked over 60% of the true quantity of energy used. Even if a second round—the inputs used to make the direct inputs—was taken into account, some 28% of the total energy consumption was omitted.

Thus, investments in what were deemed to be energy-saving projects that claimed to provide, say, a 20% net energy yield were shown by the input–output calculation as, in fact, more likely to use up more energy than they provided. They were a means to deplete rather than conserve the energy resources of society.

6. Concluding Comment

The investigation I have just described is only one example of an enormous set that demonstrates how far Wassily Leontief's work carried us beyond that of his conventionally cited predecessors. It also illustrates how invaluable are the uses to which his work can be put.

However, more than demonstrating insight and ingenuity, it shows how theory can be constructed in a way that provides a window to reality and that permits applications that *really* can contribute to the well-being of society.

Notes

1. For a deeper and authoritative study of the predecessors of input–output analysis, see Kurz & Salvadori (2000).
2. The history is described in much fuller detail in Kuczynski & Meek (1972).
3. That is not to say that the two are unrelated. In a deservedly well-recognized article Phillips (1955) shows, indeed, how the *Tableau* can be translated into an input–output model. But here the issue for us is the reverse—can anything of the input–output model be found in the *Tableau*?

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