# Anne Carter and Input-Output: Technology, Trade, and Pollution

Thijs ten Raa* and William J. Baumol**

*We pay tribute to Anne Carter's contributions to economic analysis. Mainstream economic models, including input-output studies, consider technology as given and do not question the co-existence of different national economic techniques. Carter, however, addresses this key question. Her book,* Structural Change in the American Economy *(1970), was well ahead of its time. The techniques Carter compared were differentiated by time, but the comparative analysis is equally applicable to a comparison of techniques that are differentiated by location, such as those of the EU-15 member states. We apply Carter's method for the determination of the optimal choice of technique to the problem of allocating production among different countries, so as to make use of their comparative advantages in producing commodities and in meeting environmental constraints. We also draw attention to Carter's recent work on ever deeper questions regarding variations in technology.*

Keywords : Carter, Technical change, Environmental constraints

**JEL codes: B31, O30, Q51**

The essence of the discussion that follows is the contention that the writings of Anne Carter are the most recent, though by no means the least significant, in a two and a half century series of related and deeply illuminating contributions on economic interdependencies. In a recent article devoted to the accomplishments of Wassily Leontief,

* Associate Professor of Economics, Tilburg University, the Netherlands. Department of Economics, Box 90153, 5000 LE Tilburg, the Netherlands; (T) +31-13-4662365; (F) +31-13-4663280; tenRaa@UvT.nl.

** Harold Price Professor of Entrepreneurship and Academic Director, Berkley Center for Entrepreneurship and Innovation, New York University; Senior Economist and Professor Emeritus, Princeton University; and Academic Advisor to the Ewing Marion Kauffman Foundation. Henry Kaufman Management Center, New York University, 44 West Fourth Street, Suite ~~7-91~~, New York, NY 10012, USA; (T) +1-212-998-8943; wbaumol@stern.nyu.edu.

Edit

the present authors stressed the sequence of ever richer contributions beginning with the work of Quesnay, then Marx, followed by his interpreter, Bortkiewicz. As we wrote there, Leontief's work can be seen as the culmination of a sequence that runs from the beginnings of a systematic economic literature to the end of the twentieth century. Indeed, Leontief himself repeatedly linked his work[1] with the much earlier contribution, *Tableau Économique* (1758–1759), by François Quesnay, doctor to Louis XVI. The *Tableau* is probably the earliest known writing that centers on what may be deemed a primitive general equilibrium analysis. It contains a remarkable graph that recognizes the double role of products as both inputs and outputs and traces the resulting sales, purchases, and income flows from agriculture to other main economic sectors—indisputably~~,~~ a forerunner of a modern input-output table.

Edit

The *Tableau* is often taken to have more or less disappeared from the economic literature half a century after Du Pont de Nemours left France for the United States, until it was rediscovered by Marx[2]. Marx translated the logic of the *Tableau* into his structure of "simple reproduction" under capitalism and then used it in attempting to solve what he called "the transformation problem"—derivation of the numerical relationships between his two concepts, value and surplus value, and the price and profit variables of standard economic analysis.

Marx himself suggested that his solution was imperfect (*Capital*, Vol. 3, chapter IX), and the task of providing the first fully defensible way of dealing with the problem was left to Ladislaus von Bortkiewicz (1868–1931), a distinguished Polish mathematical statistician who was born in St. Petersburg and went on to teach at the University of Berlin (Bortkiewicz, 1907 (1949)).

Bortkiewicz is relevant here for two reasons. First, the logic of his solution to the transformation problem rested directly on the Marxian model of simple reproduction—based, as Marx indicated and as we have just seen, on Quesnay. Second, as Leontief once enthusiastically recounted to one of the present authors, when he came to the University of Berlin as a postgraduate student, Bortkiewicz was appointed as his second advisor after Leontief's primary thesis advisor admitted that he could not follow his mathematics. Thus,

1 See, in particular, Leontief, W. 1928. Die Wirtschaft als Kreislauf. *Archiv fuer Sozialwissenschaft und Sozialpolitik*, 60(3), 577–623. English translation: Leontief, W. (1991). The Economy as a Circular Flow. *Structural Change and Economic Dynamics*, 2(1), 181–212.

2 See Marx's noted letter of 6 July 1863 to Engels, in which he characterizes the *Tableau* as "incontestably the most brilliant idea of which political economy had hitherto been guilty", as cited in (14), p. 75.

the chain was complete: Quesnay to Marx to Bortkiewicz to-Leontief.

However, we maintain that this story is incomplete, for it excludes the most recent step, provided when Leontief handed the torch on to Anne Carter. We know from personal experience how highly Leontief valued her knowledge and her creativity. In particular, soon after he moved from Harvard to New York University, there was an opportunity to hire a new member of the Department of Economics, and Leontief would hear of no candidate other than Carter. Unfortunately, urgent needs in a particular subfield and limited funds prevented her from receiving an offer. We are certain that Leontief never forgot his disappointment over this outcome.

## A Key Leontief Contribution: Application of Input-Output to Other Arenas

It is arguable that, as the input-output torch was passed on from one contributor to the next, substance was added at each stage. This is particularly true of Leontief himself, who expanded and deepened the underlying mathematics, showed the relevance of the analysis to economic planning, and broke through the limited role of the analysis as a fuller and deeper depiction of the interrelations of the flows that make up the activities of economies and the vessels by which these flows are carried. Arguably, however, his most creative contribution was in showing how the input-output analysis could be applied effectively to topics entailing practical applications to policy, for which it had never been used before. This observation is particularly pertinent here, as it is in this arena that some of Anne Carter's most illuminating contributions are found.

While some of the areas of application of the quantified input-output models are obvious as, for example, their use as a guide to central planning, Leontief took the applications far beyond that in sometimes unexpected directions. The application to environmental issues (Leontief, 1970), for instance, was, surely, far from obvious—though once it had been carried out, it does seem an evident and natural way to go about analyzing its subject. However, perhaps his most striking and unexpected application of input-output models was that involving international trade (Leontief, 1953), where "the Leontief paradox" has, for evident reasons, generated a stream of literature seeking to shed light on the puzzling result and draw out its implications for the field. No preceding work offered anything like the degree of flexibility and rich diversity of application present in Leontief's analysis.

Perhaps most significantly, in addition to the applications that Leontief himself was able to provide, his analysis left the way open for others to apply it in unexpected ways—taking off in still other and very different directions. There can be no clearer demonstration of the power and value of a scholarly contribution.

Input-output offers us a tool with a vast array of uses. The techniques, as noted, have been applied to subjects as heterogeneous as international trade, economics of the environment, and productivity. As such, input-output is not merely *capable* of using data; rather, it is designed for the purpose. In order to make the point that such theory of our century permits both application and use of facts, we provide a single illustration selected, in part, because it is so far afield from the topics to which input-output is commonly applied. It is also relevant here because it lies close to an area in which Anne Carter also made some of her important contributions.

The topic is energy conservation and the various projects intended to be energy-saving, among them public transportation by rail (subways), recycling of oil, and the use of solar energy and other new energy sources (Baumol, Wolff, 1981). As advocacy of such measures grew in intensity in the 1970s, dispassionate observers noted that, in addition to providing or saving energy, these processes all *used up* energy resources. For example, the agricultural products that are employed to produce biomass may be transported in trucks that use up gasoline, and the digging of subway tunnels consumes enormous amounts of power. Seeking to analyze the issue systematically, engineers invented the concept of "net energy," in which the energy used up by a proposed activity is subtracted from the energy it is expected to contribute. However, it soon became clear that engineers' calculations had at least one major shortcoming: no account was taken of the fact that it requires inputs to make inputs—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, there was a Leontief process at work. In the usual notation, if $D$ represents the vector of energy consumed per unit of output, and $A$ is the Leontief matrix, then the proper measure of energy consumed is

$$D + DA + DA^2 + \ldots + DA^n + \ldots \tag{1}$$

Most of the engineers carrying out the net energy studies were considering only $D$ as the measure of energy use. Some studies were more sophisticated and used $D + DA$ as their energy consumption measure. A still smaller number of net energy studies even subtracted

$DA^2$, but none went beyond that, thereby in effect assuming away the portion of the energy usage represented by $DA^3 + \ldots$. To provide an estimate of the magnitude of this omission, a full input-output calculation using the standard data on the US economy offered rather startling conclusions: the usual approach that takes into account only the energy of the directly used input overlooks, on average, more than 60 per cent of the true quantity of energy used. Even if a second round—the inputs used to make the direct inputs—is taken into account, some 28 per cent of the total energy consumption was shown to be omitted. As such, investments in what are deemed to be energy-saving measures that claim to offer, for example, a 20 per cent net energy yield, in fact, use up more energy than they provide, according to the input-output calculation. This result, which surely holds enormous importance for resource conservation policy, was derived completely using the input-output-approach.

It is surely important that energy consumption be reduced, not only because it saves resources for the future, but also because doing so will diminish its most threatening side-effect—the resulting carbon dioxide emissions. The US, China, and the EU-15 countries are severe polluters. The latter group, alone, emitted 350 tons of carbon dioxide per million euro gross value added in 2000 (Luksch, Steinbach, and Markosova, 2006). In North America, Asia, and Europe, the energy industry is probably a major cause of global warming. A two-way breakdown by EU member state and industry brings out the role of the energy industry in carbon dioxide emissions. Figure 1 ~~(below)~~ shows the carbon dioxide emissions for the EU-15 member states: Belgium (BE), Denmark (DK), Germany (DE), Greece (EL), Spain (ES), France (FR), Ireland (IE), Italy (IT), Luxembourg (LU), Netherlands (NL), Portugal (PT), Finland (FI), Sweden (SE), United Kingdom (UK), and Austria (AT). For each member state, five bars are displayed, each representing industries that emit carbon dioxide. From left to right these industries are: electricity, gas, water supply (E), agriculture, hunting, forestry, fishing (AB), mining and quarrying (C), transport, storage, communication (I), and manufacturing (D). Except for in Finland, the electricity, gas, and water supply industry (E) is always the greatest emitter.

Greece (EL), Germany (DE), Italy (IT), and Ireland (IE) have the greatest carbon emissions, relative to GDP. Much can be gained by acting on the recognition that world performance can be improved materially by inter-country specialization in energy production. For example, France is a clean producer of energy (41 per cent of its output is nuclear) and might well improve matters by supplying energy to Germany.

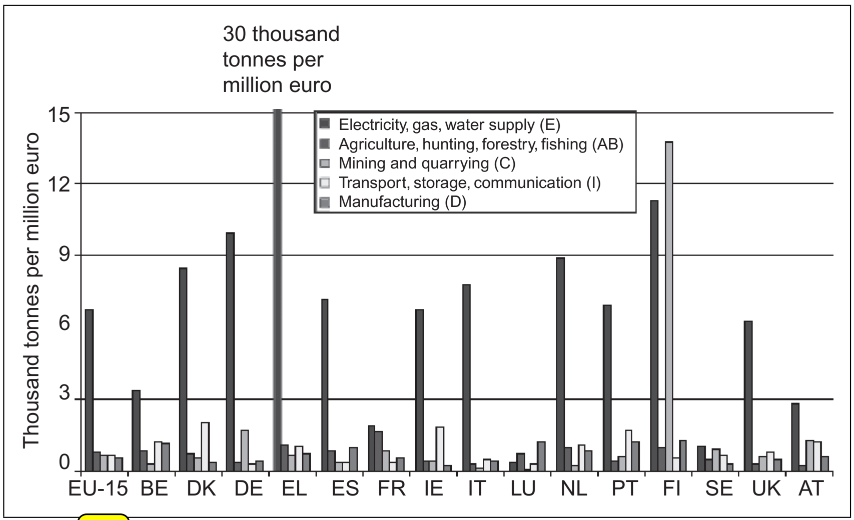


**Figure 1 : Ratio of $CO_2$ emissions and GVA by Member States (MS) and by industry in 2000, in thousand tonnes per million euro**

## A Key Carter Contribution: The Choice of Technique

It is in this arena that we encounter some of the most significant insights and contributions of Anne Carter. In standard input-output studies, technology is considered to be a given, as in all mainstream economic models, and the co-existence of different national economic techniques is not questioned. Indeed, in the models, even noncompetitive technologies are preserved via assumptions, such as fixed import coefficients or Armington variants. Carter, however, faces up to the key question—why do the differences in technology occur and persist?— using a subtle and interesting approach to deal with those differences, in the manner described below.

The adoption of more similar techniques~~,~~ as ~~substitutes for those~~ that now differentiate French and German power generation~~,~~ need not entail replacement of one mode of production by another one, but can be achieved by trade. The analysis of this option is not different from Ricardo's theory of comparative advantage, according to which, products can be produced by common techniques without necessarily adopting them at the national level. International trade is a vehicle that serves to select efficient modes of production—an old idea that has been lost in the pertinent portions of mainstream international trade theory, where endowment differences drive individual countries' choices of technique. Here, we assume that all countries have access to the same set of blueprints for techniques, as in the work of Heckscher and Ohlin. In reality, however, there are more intrinsic technology differences between countries, and this variation can be exploited to raise the standard of living in Ricardian fashion, as well as to satisfy whatever constraints are adopted to protect the environment. Reduction of global warming does not necessarily require technological advances. Much can be achieved by exploiting technical differences that already are extant, through changes in trade patterns.

Before we describe how this intuitive observation can be put to analytical use, we must have an operational understanding of the formulation that can be used explicitly to describe the varying choices of technique among countries. This task is carried out in Carter's *Structural Change in the American Economy* (~~Carter, 1970), a valuable~~ work that was well ahead of its time. The book contains an ingenious calculation, in which Carter compares an old input-output table of the US with a more recent one by constructing a hybrid model involving a choice between two techniques in each industry—one technique deemed old and the other new. The techniques Carter compared were differentiated by time, but the comparative analysis is equally applicable to a comparison of techniques that are differentiated by location, such as those of the EU-15 member states. In Carter's setting, the number of possible input-output matrices is 2 to the power equal to the number of industries, a large number. One might expect that the most efficient way to determine the changes in a bill of final demands would entail use of the information describing the technology represented by the new input-output matrix. However, Carter found an exception in the technique utilized in mining. In general, the most economical technology (that specified by the mixed input-output table) is defined by the new coefficients. Carter used these, along with the old mining coefficients, explaining that the increase of mining input coefficients did not signal technical regress, but a deterioration of the ore quality—much as in the Ricardian theory of value, where agricultural expansion necessitates the use of less fertile land. These ideas called attention to the importance of factoring in quality corrections—a new approach that became especially useful in the mining and computer industries, where traditional accounting undervalues productivity growth. In mining, this is due to input quality decreases that reduce output-input ratios, even though there has been no deterioration in technology; in computers, it is due to output quality increases and the resulting expansion in the value of output that also are not taken into account in the standard productivity calculation. Thus, modern corrections, involving hedonic pricing, can be traced back, via Carter's empirical finding, to Ricardo. More generally, her finding throws light on the productivity puzzle that quite a few industry-level Solow residuals tend to be negative, an outcome that conflicts with the dictum that increasing knowledge pushes out the production possibility frontier.

Edit

Carter's invention of an effective way to deal with issues such as construction of a huge family of input-output matrices and use of a linear program to determine the choice of technique has found its way into international trade studies that locate comparative advantages in the presence of technology differences between countries. See, for example, ten Raa and Mohnen (~~ten Raa, Mohnen,~~ 2001).

## A Model of Technology, Trade, and Pollution: Origins

Throughout her career, Carter has been far ahead of her peers. Indeed, it is only recently that the choice of technique has been recognized as an essential ingredient of applied input-output models. However, Carter's analyses in this area have long addressed the question of choice of technique.

Input-output analysis has a long tradition of assessing the role of international trade by considering export and import baskets as packages of factor contents. This goes back to the Leontief paradox (Leontief, 1953), where the US export basket was shown to be more labor intensive than the import basket. The factor content calculations of both baskets were based on a single input-output coefficients matrix for the United States.

This methodological practice also has been dominant in environmental economics (Wiedmann *et al.*, 2007), where the factor pollution is imputed to domestic consumption and net exports. This is exemplified by an influential paper by De Haan (~~De Haan,~~ 2002), in which he finds that the Netherlands' emissions exceed the contents of the country's domestic consumption. De Haan also determines that the Netherlands' main trading partner is the rest of the European Union and, moreover, that the use of Dutch input-output coefficients to assess the emission contents of imports is not too distortionary.

Different techniques are best analyzed in bilateral models. Hayami and Kiji analyze the environmental problem faced by Japan and China ~~(Hayami and Kiji, 1997)~~, using the different input-output coefficients. This approach has been extended to multi-regional models, culminating in the ongoing work of Lenzen, et al. (~~Lenzen, Pade, Munksgaard,~~ 2004). These models can be used to determine carbon footprints (and others) and to allocate the responsibility for emissions between final users.

While all of this work is very much in the spirit of Carter's analysis of coexisting techniques, her ideas remain ahead of the literature because she addresses the question of choice of technique. Indeed, most input-output models, including the recent multi-regional ones, duck the question entirely by assuming that economies have their own techniques *and* that these are maintained, even in the face of international competition, by imposing fixed import coefficients.

## A Model of Technology, Trade, and Pollution: Application

In order to demonstrate this, we now apply Carter's method for the determination of the optimal choice of technique to the problem of allocating production among different countries, so as to make use of their comparative advantages in producing commodities, while meeting environmental constraints.

In our setting, the number of conceivable input-output matrices is 15 to the power equal to the number of industries, a number beyond imagination. However, Carter's trick is to reduce the magnitude of the problem of optimal choice of technique (in our setting, the optimal pattern of specialization between member states) by means of a linear program. The idea is best illustrated for a two-country world, since extension to 15 or even more countries entails no additional conceptual or computational complications.

Here, we will use Roman bloc letters for symbols that refer to one country and italics for the other country. The input-output coefficients matrices are denoted $\mathrm{A}$ and $A$, respectively. Similarly, the labor coefficients are denoted by row vectors, $\mathrm{l}$ and $l$. If there are different types of labor, vectors $\mathrm{l}$ and $l$ become matrices. These matrices can also accommodate other factor input services—for example, that of capital. The gross output vectors are $\mathrm{x}$ and $x$, and the net output vectors (that is, the nets of intermediate demands, $\mathrm{Ax}$ and $Ax$) are $\mathrm{y}$ and $y$. In this constant-returns-to-scale economy, the standard welfare theorems hold, and therefore, the Walrasian economic equilibrium can be determined by finding the optimal solution for the model (Arrow, 1951; Debreu, 1959).

In principle, one needs information regarding consumer preferences to carry out this procedure, but a conservative criterion can be satisfied by assuming an expansion of the levels of all final demands, without changing their proportions (ten Raa, 2008). Hence, to describe the process, we will consider final demands, $\mathrm{cy}$ and $cy$, where $\mathrm{c}$ and $c$ are expansion factors to be maximized. It is always possible to expand one economy at the expense of the other by shipping products, so the question is what the proportion between the expansion factors ideally should be. Let $c = \gamma \mathrm{c}$. This equation leaves us with a single criterion, $\mathrm{c}$. The proportion, $\gamma$, will be determined by the balance of payments between the two economies, with outputs constrained by the quantities of resources available. At this point, these constraining resource quantities are the sizes of the labor forces, $\mathrm{L}$ and $L$. The model that encompasses the calculations of the optimal assignment of production tasks reads

$$\max_{\mathrm{x}\geq 0,\, x\geq 0,\, \mathrm{c}} \mathrm{c} \text{ subject to}$$
$$\mathrm{x} + x \geqslant \mathrm{Ax} + \mathrm{cy} + Ax + \gamma \mathrm{c}y,\ \mathrm{lx} \leqslant \mathrm{L},\ lx \leqslant L. \tag{2}$$

We denote the shadow prices of the constraints by row vector, p, and scalars, w and *w*. The vector of quantities traded is implicit. As such, Country 1's net exports are x - Ax - cy. If this is valued in terms of the commodity shadow prices, the balance of payments is expressed by, p(x - Ax - cy). If gamma is zero, the balance is negative (i.e., the other economy produces only to help the first economy). If the opposite is true, and gamma is infinity, the balance is positive. Using the intermediate value theorem, we find that gamma is zero for some value of gamma—the general equilibrium. The model will allocate the production of any product to one country or the other. This is indicated by the sign patterns of the components of the optimal gross output vectors, x and *x*.

Next, we bring in emissions coefficients row vectors, b and *b*.

$$\max_{\mathrm{x}\geq 0,\, x\geq 0,\, \mathrm{c}} \mathrm{c} \text{ subject to}$$

$$\mathrm{x} + x \geqslant \mathrm{Ax} + \mathrm{cy} + Ax + \gamma \mathrm{c}y,\ \mathrm{lx} \leqslant \mathrm{L},\ lx \leqslant L,\ \mathrm{bx} \leqslant \mathrm{B},\ bx \leqslant B. \quad (3)$$

Here, B and *B* are emission ceilings set by some decision process, such as that underlying the Kyoto treaty. Note that this is formally equivalent to bringing in a second constraining scarce resource (such as capital). The shadow price of an emissions constraint is equivalent to a capital rental rate, but now its role is assumed by a Pigovian tax or, equivalently, an emissions rights fee. As usual, the price serves to limit the social damage caused by the emissions by making such undesirable behavior expensive for the emitter. By finding the prices implicit in the solution of the linear programming problem (3), one obtains the incentive that leads to the optimal balance between the reduction of the emissions in question and the cost of attaining that reduction.

This charge affects all commodity prices in a general equilibrium way, with the new prices revealed by the dual conditions associated with linear program (3). Apart from an uninteresting normalization constraint, these price conditions are given by equation (4).

$$\mathrm{p} \leqslant \mathrm{pA} + \mathrm{wl} + \mathrm{rb},\ \mathrm{p} \leqslant \mathrm{p}A + wl + rb. \quad (4)$$

Wage rates w and *w* are country specific, but the commodity prices, given by vector p, are not. The emissions rights fees, r and *r*, are specific, so long as the constraints are country specific. Even in the latter situation, the model shows that international trade is a vehicle that enables environmental constraints to be met. If an emissions coefficient is high in one country, while the other coefficients are similar, then linear program (3) will allocate production to the other country. *The straightforward logic of this result mirrors the Ricardian principle of specialization according to comparative advantage*. Both are effective ways to reduce emissions. In effect, this benefit is the form taken by the gains from trade in the analysis here. However, for the market mechanism to achieve this result, emissions rights must be priced and reflected in the costs of production, as seen in equation (4). We say equation, rather than inequality, because the complementary slackness of the theory of linear programming tells us that a strict inequality requires the activity variable in question (a gross output component) to be zero. As such, only the binding constraints in (4) are relevant.

It is also interesting to observe that we may pool the emission constraints, $\mathrm{bx} + bx \leq \mathrm{B} + B$, which is the equivalent of adopting tradable emission rights. This will raise the standard of living even further and is equivalent to the satisfaction of pollution constraints via a tradable license arrangement that enables the reduction of emissions to be carried out by those polluters who can do so most efficiently—that is, at lowest resources cost. In sum, much can be said for this mechanism, which effectively exploits the room provided by technology variation in order to reduce emissions at minimum real cost.

## A Tribute to Anne Carter

To summarize, this market mechanism allocates production among countries efficiently and in a manner consistent with environmental constraints. The essence of this allocation is described and effectively analyzed by a linear program that models the choice among techniques—a powerful construct first devised and used by Anne Carter in her study of structural change. That contribution, alone, demonstrates Carter's outstanding ability to undertake pure analysis, as well as to design policy that promises to improve to the general welfare. Leontief's material balances are consistent with the Walrasian idea of general equilibrium, in the sense that supply equals demand as physical quantities, but not yet in the sense of consistent behavior between maximizing producers and consumers. Carter broke the chain of analyses of the role of economic interdependencies that extends from the contribution of Quesnay to those of Leontief by opening it up to Walras and taking it to applications involving choice.[3]

3 The authors are grateful to our editor, Amanar Akhabbar, for the suggestion that we add this observation about the relevance of Carter's work to that of Walras.

Moreover, Carter's book on change (Carter, 1970) has been influential and continues to guide us in our research. However, she has moved on from analyzing the choice of technique to address ever deeper questions. The implementation of a new technique, *even when it is available elsewhere*, requires knowhow. In turn, the acquisition of knowhow is complex, and Carter (~~Carter, 1989) analyzes how~~ this process differs from that of obtaining ordinary capital, in terms of accounting, and co-determines the diffusion of technological knowledge. Carter also addresses the mind-boggling economic measurement issues that emerge when technical change—in the broader sense of not only new processes, but also new products—affects product and industry classifications (Carter, 1998). In this way, Carter continues to set the research agenda.

## References


Arrow, K.J. 1951. An Extension of the Basic Theorems of Classical Welfare Economics. *Proceedings of the Second Berkley Symposium on Mathematical Statistics and Probability*, Berkley, California: University of California Press.

Baumol, W.J., Wolff, E.N. 1981. Subsidies to New Energy Sources: Do They Add to Energy Stocks? *Journal of Political Economy*, *89*(5), 891–913.

Bortkiewicz, L. von. 1907 (1949). On Correction of Marx's Fundamental Theoretical Construction in the Third Volume of Capital. In: *Jahrbűcher fűr Nationalőkonomie und Statistik*, translated by Paul M. Sweezy in: *Karl Marx and the Close of his System*, New York: Augustus M. Kelley: 199–221.

Carter, A. 1970. *Structural Change in the American Economy*. Cambridge: Harvard University Press.

Carter, A. 1989. Knowhow Trading as Economic Exchange. *Research Policy 18*(3), 155–163.

Carter, A. 1998. Measuring the Performance of a Knowledge-Based Economy. In: *The Economic Impact of Knowledge*, edited by Dale Neef, Gerald Anthony Siesfeld, and Jacquelyn Cefola, Boston: Butterworth-Heinemann, 203–211.

Debreu, G. 1959. *Theory of Value*. New York: Wiley.

De Haan, M. 2002. Disclosing International Trade Dependencies in Environmental Pressure Indicators: The Domestic Consumption Perspective. *In Fourteenth International Conference on Input-Output Techniques, Montréal, Canada*, edited by C. DeBresson.

Hayami, H., Kiji, T. 1997. An Input-Output Analysis on Japan-China Environmental Problem: Compilation of the Input-Output Table for the Analysis of Energy and Air Pollutants. *Journal of Applied Input-Output Analysis 4*, 23–47.

Lenzen, M., Pade, L.-L., Munksgaard, J. 2004. $CO_2$ Multipliers in Multi-Region Input-Output Models. *Economic Systems Research 16*, 391–412.

Leontief, W. 1953. Domestic Production and Foreign Trade: The American Capital Position Re-Examined. *Proceedings of the American Philosophical Society 97*(4), 332–349.

Leontief, W. 1970, Environmental Repercussions and the Economic Structure—An Input-Output Approach, *Review of Economics and Statistics 52*(3), 262–270.

Luksch, U., Steinbach, N., Markosova, K. 2006. Economic Activities and Their Pressure on the Environment 1995–2000, *Eurostat Statistics in Focus*, Environment and Energy.

Phillips, A. 1955. The *Tableau Économique* as a Simple Leontief Model. *Quarterly Journal of Economics*, *69*(1), 137–144.

ten Raa, Th., Mohnen, P. 2001). The Location of Comparative Edit
Advantages on the Basis of Fundamentals Only. *Economic Systems Research*, *13*(1), 93–108.

ten Raa, Th. 2008. Debreu's Coefficient of Resource Utilization, the Solow Residual, and TFP: The Connection by Leontief Preferences. *Journal of Productivity Analysis*, *30*, 191–199.

Wiedmann, T., Lenzen, M., Turner, K., Barrett, J. 2007. Examining the Global Environmental Impact of Regional Consumption Activities—Part 2: Review of Input-Output Models for the Assessment of Environmental Impacts Embodied in Trade. *Ecological Economics*, *61*(1), 15–26.