STATE OF NEW MEXICO
BEFORE THE ENVIRONMENTAL IMPROVEMENT BOARD

IN THE MATTER OF PROPOSED REGULATION 20.2.350 NMAC – *GREENHOUSE GAS CAP AND TRADE PROVISIONS* **No. EIB 10-04 (R)**

REBUTTAL TESTIMONY OF ADAM ROSE

In this rebuttal testimony I will address certain aspects of the testimony submitted by Dr. Darek Nalle (PNM), Dr. Anne Smith (Tri-State), Drs. Terry Crawford and Jay Lillywhite (City of Farmington), Mr. Paul Bachman (NMOGA), and Mr. Jack Ihle (SPS).

I. <u>REBUTTAL TO TESTIMONY OF DAREK NALLE</u>

Dr. Nalle concludes that the NMED's proposed climate policy proposal will lead to a 0.30% to 0.62% reduction in gross state product (GSP) and a reduction of 0.31% to 0.66% reduction in employment in New Mexico. These GSP estimates are within the range of three of the seven policy scenarios simulated in my study "Macroeconomic Impacts of the New Mexico Cap-and-Trade program on the state's economy: A REMI Analysis." One of the scenarios we simulated resulted in employment losses as high as 0.26% (see Table ES-2).

While I noted that most likely outcome of the proposed policy would be slightly positive--on the order of 0.13 to 0.17% in GSP and 0.18 to 0.22% in employment (see Table ES-2), these results are still very close to the numerical losses projected by Nalle. Thus, the results of the two studies are well within the empirical margin of error in evaluating such complex issues.

Let me address the following statements in Nalle's testimony:

NALLE'S STATEMENT:

> First, the NMED analysis includes questionable assumptions that obscure the cost to New Mexico. The NMED's analysis inappropriately mixes economic benefits from complementary policies with the economic costs of a cap & trade program. This practice masks the costs of the cap & trade program. (Nalle at 4, ll. 5-8).

RESPONSE: This issue will be addressed by the rebuttal testimony of Sandra Ely.

NALLE'S STATEMENT:

> The supply-side energy assumptions in the analysis appear too optimistic, resulting in declines in energy prices that are not found in other analysis of cap & trade programs. It is noteworthy that NMED's analysis finds lower energy prices despite the application of a price on GHG emissions and the cost of cleaner energy supplied investments. (Nalle at 4, ll. 12-16).

RESPONSE: Our estimates of price reductions of electricity differ from most other studies in that we assume, in a manner consistent with the NMED proposal, that emission allowances will be granted without cost. Under an auction scenario, there is a justification for a price increase to be approved by a public utility commission due to the expenditure on allowances by emitters. In the free-granting case, there is not. Costs increase only as a result of steps taken by emitters to reduce emissions. ENERGY2020 identifies several low-cost and even cost-saving methods to do so. Thus, there is only a slight upward shift in the electricity supply curve. At the same time, ENERGY2020 projects a significant reduction in demand for electricity because of energy efficiency improvements. This downward shift in demand places downward pressure on electricity prices. The interaction of supply and demand results in an overall decrease in electricity prices in most of our scenarios, because of the dominance of demand-side effects.

However, there were two scenarios in which we also projected the possibility of electricity price increases.

NALLE'S STATEMENT:

> The NMED analysis shows that New Mexico's covered entities will be purchasing more than 50% of their emissions reductions through allowances and offsets form other states. (Nalle at 5, ll. 2-3).

RESPONSE: These allowance purchases will be less expensive than the alternative of New Mexico undertaking emission reductions on its own.

NALLE'S STATEMENT:

> Finally, the NMED proposal is likely to result in economic leakage or loss of industries and jobs to other states without similar state-level caps. All of in-state industries are projected to be adversely affected by the cap, including net losses of green jobs. (Nalle at 5, ll. 11-13).

RESPONSE: Our analysis shows that few industries are likely to lose jobs as a result of the proposed rule. Moreover, there is no indication that any green jobs, in particular, will be lost.

NALLE'S STATEMENT:

> Rose testimony (RT) uses one of the major, commonly-used, input-output (I-O) economic models for regional economic analysis. (Nalle at 5, ll. 6-7).

RESPONSE: The Regional Economic Models, Inc. (REMI) Policy Insight Plus (PI^+) Model is not just an input-output model. It is a complex multi-faceted model. For example, it includes a full-blown labor/demographic model that captures non-linear supply and demand forces that are brought into equilibrium by changes in the wage rate.

It allows for substitution between labor, capital, and energy aggregates through a Cobb-Douglas production function. It also includes features of regional competitiveness by assessing the relative prices of domestically produced and outside competing products. The I-O analysis used by Nalle is a rudimentary tool that is nowhere as sophisticated and capable of accuracy as a model such as REMI.

NALLE'S STATEMENT:

> However, the RT's assumptions drive its results...yet the RT does not estimate cap & trade regulation in and of themselves [sic]. Intertwined in all its scenarios are outputs from the ENERGY2020 model and the assumed implementation of complementary policies (CP), which stand for the mass negative statewide impacts of the proposed cap & trade regulations. (Nalle at 6, ll. 15-21).

RESPONSE: Yes, our analysis does use the ENERGY2020 model results, which were commissioned by the Western Climate Initiative (WCI). The WCI vetted these results through public meetings and comment periods. The rebuttal testimony of Karl Hausker will address the soundness of the ENERGY2020 analysis and its consistency with the analysis in my report.

NALLE'S STATEMENT:

> In fact, if all of the RT's assumptions came to bear, then this testimony would concur with that of RT. (Nalle at 6, ll. 11-13).

RESPONSE: This is not the case because the REMI Model and the EMSI Model differ in major ways. I-O is the most basic of all macroeconomic models. It is essentially a linear model of all purchases and sales between sectors of an economy, based on the technological relationships of production. It is thus static, linear, and lacks any behavioral content. It also ignores the role of markets and prices. Moreover, I-O analysis is uni-directional, which means that if a negative, or cost-incurring mitigation option, is injected into the model, the macro impacts will automatically fall in the same direction. No offsetting factors, such as price changes or input substitution that might lead to more sophisticated assessment. Early in my career I employed I-O analysis in my research, but found it unsatisfactory for sophisticated work involving behavioral responses, the workings of markets, and major macroeconomic interactions. Although I became a leading authority in the field (NMED-Rose Rebuttal Exhibit 1), I only use I-O in the most dire circumstances in which budgets and time are limited, and then acknowledge the model's severe limitations in presenting my results.

NALLE'S STATEMENT:

> To have confidence in the RT's results, one must accept a host of assumptions—some of which may be heroic. (Nalle at 7, ll. 1-2).

RESPONSE: The validity of the assumptions relating to the ENERGY2020 input data are substantiated by the testimony by Dr.Hausker.

II. <u>REBUTTAL TO TESTIMONY OF ANNE SMITH</u>

Anne Smith's main point can be summarized in her statement, "When the effects of policies that are not included in the NMED proposal are removed from Rose's and Hausker's respective analyses, one can observe that rather than the NMED proposal having economic benefits, NMED's own economic experts are projecting negative economic impacts for the cap-and-trade elements in every scenario they have considered" (p. 3, ll.12-16). This contention is based on two erroneous premises: (1) Complementary

Policies (CPs) are not part of the NMED policy proposal; and (2) we have modeled Cap-and-Trade (C&T) incorrectly. Karl Hausker's testimony addresses the first premise. Here, I will focus on the second premise.

Q. SMITH ASSERTS THAT THE ECONOMIC BENEFITS OF CPS ARE NOT WELL-ESTABLISHED BY MAINSTREAM ANALYSIS (p. 1, ll. 1-2). DO YOU AGREE?

A. No. There is an increasing awareness that many mitigation options represent cost-savings. This awareness is reflected in the reports of the IPCC, the findings of stakeholder groups in 16 states (Center for Climate Strategies, 2010; http://www.climatestrategies.us/ewebeditpro/items/O25F23386.PDF), and the research of mainstream economists such as Professor James Sweeney of Stanford University.

Q: SMITH ASSERTS THAT YOU AND DR. HAUSKER USED DIFFERENT SETS OF ENERGY 2020 MODEL RUNS, MAKING IT IMPOSSIBLE TO COMPARE OR TRACE YOUR RESULTS. DO YOU AGREE?

A: No. The Energy 2020 model runs are essentially the same. My analysis performed a bounding analysis around the $33/ton runs performed by Dr. Hausker.

Q: SMITH ASSERTS THAT BECAUSE YOUR MODEL IS DIRECTLY LINKED TO THE OUTPUTS OF DR. HAUSKER'S MODEL, YOUR MODEL MERELY TRANSLATES THE FINDINGS OF DR. HAUSKER'S

MODEL INTO POSITIVE OR NEGATIVE IMPACTS TO MACROECONOMIC VARIABLES (p. 5, fn. 3). DO YOU AGREE?

A. No. REMI is a sophisticated model that does not yield as mechanical a set of results as conjectured. REMI contains many interacting macro relationships. For example, my report reflects both positive and negative macro impacts for the range of policy cases that do not mimic the outputs of Dr. Hausker's Energy 2020 runs. See also the results of my reports on the different policy options analyzed with REMI for the states of Pennsylvania, Michigan and Wisconsin as well the REMI website (http://www.remi.com/index.php?page=model&hl=en_US).

Q: SMITH ASSERTS THAT YOU ERRED IN SUGGESTING THAT THE $5/TON CASE APPROXIMATES THE NMED'S PROPOSED POLICY (p. 10, ll. 27-30). DO YOU AGREE?

A: No. The $5/ton case is the closest approximation available for analyzing New Mexico's free-granting policy. There is some ambiguity at this time in just how other WCI states will allocate their allowances—auction or free.

Q: SMITH ASSERTS THAT YOUR STATEMENT REGARDING ENERGY 2020'S ABILITY TO PREDICT THE IMPACTS OF FREE ALLOWANCES CONTRADICTS THE WCI MODELING EFFORT (p. 10, ll. 10-15). DO YOU AGREE?

A: No. This is a misrepresentation of the my testimony. My point refers not to limitations of the Energy 2020 model, but to the fact that a simulation of the free-granting case was not available.

Q: SMITH ASSERTS THAT MY CONCLUSION REGARDING THE EFFECT OF FREE ALLOWANCES CONTRADICTS THE WCI MODELING EFFORT AND IS INCONSISTENT WITH ECONOMIC THEORY AND EMPIRICAL ANALYSIS OF EMISSIONS TRADING POLICY (p. 10, ll. 15-23). HOW DO YOU RESPOND?

A: Granting free allowances is likely to result in a zero cost pass-through to customers of electric utilities in the current regulatory environment. Imagine a utility approaching a public service commission and asking for a rate hike on the basis of the "opportunity cost" of the allowances. Many policy analysts, state government officials, and public service commissions have expressed their resistance to the standard argument in economic theory that the opportunity cost of the allowance should be included in the price of the final good or service being produced (see, e.g., http://docs.cpuc.ca.gov/word_pdf/FINAL_DECISION/ 92591.pdf). That argument is based solely on the criterion of economic efficiency, and there are several other worthy policy criteria to consider, such as equity or fairness. Most impartial observers would consider giving a utility a potentially valuable asset and then granting the utility a price increase when the utility claims this asset as a cost rather than a gain quite objectionable in the broader context of public policy. Not allowing the utility to pass on the opportunity cost to customers keeps electricity prices low and protects low-income consumers, for example. Note that in the free-granting case, our analysis <u>does</u> allow the utility to pass on the cost of compliance to customers. But it does <u>not</u> allow any of the difference between mitigation costs and allowance price (the remaining opportunity cost) to be passed through to the customer. In the case of sectors other than utilities, such as the oil and gas industry, free allowances are often justified on equity grounds of transition assistance and preservation of competitiveness. The latter cannot be realized by firms that compete in national and international markets if they raise their prices on the basis of opportunity cost

Q: SMITH ARGUES THAT "REAL WORLD EMPIRICAL EXPERIENCE WITH ACTUAL TRADING SYSTEMS" CONTRADICTS YOUR "IMPLICATION THAT FREE ALLOCATIONS DRIVE ALLOWANCE PRICES TO ZERO" (p. 11, ll. 2-5). DO YOU AGREE?

A: No. The issue is not the allowance price, but rather the extent to which the opportunity cost of allowances can be passed on to customers and consumers.

Q: SMITH CONTENDS THAT THE OPPORTUNITY COST DOES EFFECT THE ECONOMIC ANALYSIS (p. 11, ll. 21-26). WHAT IS YOUR RESPONSE?

A: The assumption that the free-granting of allowances would not, by itself, affect the price of products in those sectors receiving free allowances is not inconsistent with a market being formed for allowances at a positive price.

Q: SMITH CONTENDS THAT I CONFUSE ALLOWANCE PRICES FACED BY COMPANIES WITH THE PASS-THROUGH OF ALLOWANCE PRICES TO CONSUMERS BECAUSE SOME COMPANIES MAY USE THE FREE ALLOWANCES TO AVOID PASSING THROUGH THE MARKET PRICE OF ALLOWANCES THEY MUST PURCHASE (p. 12, ll. 14-18). HOW DO YOU RESPOND?

A: Smith is now agreeing with me. This is exactly what I have been saying all along. I never claimed that the market price of allowances would be zero; my emphasis was on the cost pass-throughs.

Q: SMITH ARGUES THAT "WHEN THE CONSUMERS DO LESS THAN WOULD BE OPTIMAL UNDER FULL PRICE PASS-THROUGH, MORE EMISSION REDUTIONS HAVE TO OCCUR ELSEWHERE IN THE ENERGY SYSTEM, AND THAT MEANS THE ALLOWANCE PRICE WILL HAVE TO BE HIGHER THAN IT WOULD HAVE BEEN WITHOUT THE FREE ALLOCATIONS" (p. 12, fn. 14). WHAT IS YOUR VIEW?

A: It is not clear that consumers will do less than optimal. Moreover, not allowing opportunity costs to be passed through will mean less price pressure on customers. This is likely to involve a larger cost break to the customers of firms that receive free-granted allowances than any price increase on allowance purchases even at the higher price suggested by Dr. Smith. The number of free-granted allowances will far exceed the number of allowances that are traded by New Mexico entities under the proposed policy.

Q: SMITH ASSERTS THAT YOUR ANALYSIS IS FLAWED BECAUSE YOU ASSUME THAT ALLOWANCE PRICES WOULD BE REDUCED BY THE NMED'S PLAN FOR FREE ALLOCATION (p. 13, ll. 6-8). HOW DO YOU RESPOND?

A: As I stated earlier, my analysis does not imply a reduction in the market allowance price.

Q: SMITH SUGGESTS THAT YOUR TABLE ES1 CONTAINS A TYPOGRAPHICAL ERROR FOR THE GSP ESTIMATE FOR THE CAP20+CP CASE. (p. 20, fn. 25). IS THIS TRUE?

A: No. Smith misreads Table ES1. The numbers in the first two numerical columns are for different time periods. The GSP impacts in terms of a change in its level are for the entire policy horizon of 2012-20, while the percentage change is listed only for the last year, 2020. It is possible for the net change over eight years to be positive, while the change for any single year is negative. This seemingly awkward presentation is necessitated by the difficulty of providing a meaningful percent change for the net present value of changes in the level of impacts, and the state's interest in providing additional information for the end year of 2020.

Q: SMITH ASSERTS THAT YOU HAVE CLAIMED THAT NEW MEXICO BUSINESS WILL NOT FACE AN ALLOWANCE PRICE UNDER

NMED'S FREE ALLOCATION PROPOSAL (p. 22, ll. 22-23). IS THIS TRUE?

A: No. This is a misrepresentation of my analysis. A market can be established in New Mexico alone or in the context of the broader WCI that would, of course, need to have a positive allowance price.

Q: SMITH COMPLAINS THAT "LAWMAKERS" DISTORT THE MARKET BY IMPOSING REGULATORY MANDATES (p. 26, ll 27-30). HOW DO YOU RESPOND?

A: It is not clear whether Smith is complaining about the NMED proposal for a cap-and-trade program or just voicing a philosophical position. Regardless of the context, however, Smith ignores the existence of market failure, which inhibits the attainment of the most efficient outcome. We should not settle for a failed market outcome, and government policies provide an important complement to market mechanisms in achieving environmental goals.

Q: SMITH ASSERTS THAT "UNLESS THE COMPLEMENTARY POLICIES CORRECT MARKET FAILURES WITHOUT IMPOSING ADDITIONAL COSTS, THEY CAN ONLY SUBSTITUTE MORE COSTLY GHG CUTS FOR THOSE THAT COULD HAVE BEEN MADE AT LOWER COST (p. 27, ll. 5-9). DO YOU AGREE?

A: This argument is incorrect if the marginal cost curve of complementary policies is lower than the marginal cost curve of price-responsive policies, or when price-responsive policies are exhausted.

III. REBUTTAL TO TESTIMONY OF CRAWFORD AND LILLYWHITE

The analysis by Crawford and Lillywhite (C&L) is far too cryptic to be useful:

- Basic variables are not defined in Table 1.
- Basic data from Weaver and Michel[1] are not explained.
- There is no explanation for how the key variables are incorporated into the analysis.
- There is no consideration of mitigation cost savings or technological change.

C&L use multipliers from an input-output (I-O) model to evaluate the proposed rule. I-O is the most basic of all macroeconomic models. As explained in my rebuttal to the Nalle testimony, I-O analysis is a poor choice for sophisticated work and suffers from severe limitations.

I-O is not appropriate for analyzing the macroeconomic impacts of climate change policy. Here, C&L appear to have used the crudest form of the model - simple impact multipliers from the Impact Analysis for Planning (IMPLAN) System. One major flaw of the IMPLAN multipliers is that they tend to err significantly on the high-side for small regions because of their implicit assumption that capital-related income generated in a county or state is paid to and spent in that same geographic area. Significant leakage arises because of absentee ownership of natural resources and businesses. The income payments are thus "transboundary flows" that leak out of the multiplier process. For example, C&L ascribes a multiplier of 1.6974 to the Oil and Gas Industry in San Juan County, which is inordinately high for that small a region. I have done a detailed study of this general topic in my paper "Transboundary Flows of Capital-Related Income,"

[1] I have been informed that Mr. Michel is not a Department witness, and his statements are not testimony in this proceeding.

published in *The Journal of Regional Science*, the leading academic forum in this field. NMED-Rose Rebuttal Exhibit 2.

IV. <u>REBUTTAL TO TESTIMONY OF PAUL BACHMAN</u>

Mr. Paul Bachman uses a combination of two models to perform an analysis of the macroeconomic impacts of the proposed rule, but neither model is calibrated to New Mexico-specific data. Moreover, neither model should be considered adequate to the task at hand.

The RICE model was developed by Richard Nordhaus, a prominent economist, to examine broad-brush issues relating to climate change policy at the regional and international levels. As a regionalized world model, RICE must be down-scaled using the "Other High-Income Region" consisting of the U.S. and other countries such as Australia, Canada, Hong Kong, South Korea, Macao, New Zealand, and Singapore. The model also is highly aggregated in terms of the number of sectors and economic interactions. As a result, "down-scaling" the RICE model to an individual state such as New Mexico goes beyond sound modeling practice.

RICE is designed for long-run projections out to the year 2100, and is run in 10-year increments; hence Bachman's use of the results for 2025. Typically, the model leads to estimates of carbon taxes or allowance prices higher than the average of climate policy impact models (see, e.g., the recent IGCC reports).

Bachman also used a computable general equilibrium (CGE) model in its analysis. However, Bachman does not have a New Mexico version of the model, and thus was forced to use models for five other states, none of them resembling New

Mexico, to draw inferences about the proposed rule. See Bachman at 10, ll. 3-10 (admitting the significant limitations of not using a New Mexico-specific model).

While CGE is a powerful tool in general, its crude application to evaluating the macroeconomic impacts of climate change policy has been challenged in many contexts. CGE's shortcomings include:

- Limited data inputs.
- Borrowing elasticities of substitution and other import parameters from the general literature rather than estimating them for the region in question.
- Assuming the economy is always in equilibrium and all economic decision-makers are maximizing their behavior.

Moreover, Bachman's testimony in this case is too cryptic to evaluate the details of his model but his previous applications of the CGE model to climate change policy typically incorporated only a limited number of mitigation options, and the major one modeled is the substitution between inputs such as inter-fuel substitution among fossil fuels. The model did not include the potential role of renewables and other types of technological improvements. In addition, there is no specification for energy efficiency improvements (a major category of conservation). Thus, all responses in the model are biased - they are all modeled as cost-incurring. As a result, there is no possibility of a cost-saving option in the model.

I recently undertook a study of more than three dozen models used to estimate the macroeconomic impacts of climate change policy. NMED-Rose Rebuttal Exhibit 3.. Using a sophisticated statistical analysis, I found that the major factor influencing the results was whether the direct cost of mitigation was modeled as being positive or negative. Thus, it is not surprising that Bachman projects negative impacts of climate change policy in every state that it has conducted an analysis.

Bachman's sensitivity analyses appear to be especially crude - the high and low estimates are exactly 50 percent above and below the base results. This is curious in a basically non-linear model, and implies that the sensitivity analyses were not really run through the model, but simply done through a back of the envelope calculation with the final results.

IV. REBUTTAL TO TESTIMONY OF JACK IHLE

Q. MR. IHLE ASSUMES THAT BECAUSE OTHER ANALYSES OF GHG CAP-AND-TRADE PROGRAMS FORECAST INCREASES IN ELECTRICITY PRICES, THE DEPARTMENT'S PROPOSAL ALSO WILL INCREASE SUCH PRICES (p. 8). HOW DO YOU RESPOND?

A. The free granting of allowances will help relieve upward pressure on electricity prices in New Mexico. The New Mexico case differs from other legislation referred to by Ihle, which include a significant amount of allowance auctioning. Moreover, efficiency improvements in electricity use will shift the demand curve downward, and if these cost-savings are relatively large, they could lead to price decreases.

Q. MR. IHLE QUESTIONS YOUR RESULTS SHOWING LOWER ELECTRICTY PRICES IN THE REFERENCE CASE AND CITES

OTHER STUDIES WITH DIFFERENT CONCLUSIONS. (p. 13-14). HOW DO YOU RESPOND?

A. Again, there is a major difference between my analysis and the ones cited by Ihle. In my analysis, granting free allowances is likely to result in a zero cost pass-through to customers of electric utilities in the current regulatory environment. Not allowing the utility to pass on the opportunity cost to customers will keep electricity prices low and protect low-income consumers, for example. Note that while the free-granting case does not allow the utility to pass on the cost of compliance to customers, it does allow any of the difference between mitigation costs and allowance price (the remaining opportunity cost) to be passed through to the customer. Still this factor is offset by the downward pressure on electricity prices stemming from energy efficiency improvements.

Q. HOW DO YOU RESPOND TO THE ASSERTION THAT ALLOWANCE ALLOCATION METHODS DO NOT ALTER THE ALLOWANCE PRICE BECAUSE MARKET PRICES ARE DETERMINED BY THE COST OF EMISSION REDUCTIONS? (p. 14-15)?

A. I agree that the costs of actual mitigation will affect prices. However, most of the price increases in some studies cited by Ihle also pass along the opportunity cost of free allowances (see also the testimony by Anne Smith).

5. See Statistical Office of the European Communities (1979), No. 267.
6. See also the considerations of the United Nations on the breakdown of inputs of the sectors according to functions (among others current production, environmental protection, research): United Nations (1975).
7. For the recording of assets see Schäfer (1986).
8. There are at present no data available on internal environmental protection services of agriculture, trade, transport and other service enterprises. They are however of only minor quantitative importance.
9. For other categories of defensive expenditure that could be considered in the computation of a welfare measure, see Leipert (1984), NNW Measurement Committee (1973) and Nordhaus & Tobin (1972).
10. See Samuelson (1962), p. 33 ff.
11. See Nordhaus & Tobin (1972); NNW Measurement Committee (1973).
12. The authors are obliged to U.P. Reich and A. Ryll for clarifying discussions on this subject.
13. See Stahmer (1986), p. 104 ff.

References

Beutel, J. & Stahmer, C. (1982) 'Input-Output-Analyse der Energieströme', *Allgemeines Statistisches Archiv*, No. 3.

Bonhoeffer, F.O. & Britschkat, G. (1973) 'Der zentrale und der regionale Gesichtspunkt bei Input-Output-Analysen, *Wirtschaftskonjunktur*, No. 3.

Britschkat, G. (1973) 'Zur Abhängigkeit der Bruttoproduktion und der Importe von der Endnachfrage', *Wirtschaftskonjunktur*, No. 1.

Herfindahl, O.C. & v. Kneese, A. (1973) 'Measuring Social and Economic Change: Benefits and Costs of Environmental Pollution', in: Moss, M., ed., *The Measurement of Economic and Social Performance* (New York) p. 441 ff.

Leipert, Chr. (1986) 'Social costs of economic growth', *Journal of Economic Issues*, 20, 1.

Leontief, W. (1973) 'National Income, Economic Structure, and Environmental Externalities', in: Moss, M., ed., *The Measurement of Economic and Social Performance* (New York), p. 565 ff.

Leontief, W. & Ford, D. (1972) 'Air Pollution and the Economic Structure: Empirical Results of Input-Output Computations', in: Brody, A. & Carter, A.P., *Input-Output Techniques* (Amsterdam and London), p. 9 ff.

NNW Measurement Committee (1973) *Measuring Net National Welfare of Japan* (Tokyo).

Nordhaus, W. & Tobin, J. (1972) 'Is Growth Obsolete?', in: National Bureau of Economic Research, General Series No. 96.

Samuelson, P.A. (1962) 'The Evaluation of 'Social Income': Capital Formation and Wealth', in: Lutz, Hague, ed., *Theory of Capital*, p. 32 ff.

Ryll, A. & Schäfer, D. (1986) 'Bausteine für eine monetäre Umweltberichterstattung', *Zeitschrift für Umweltpolitik und Umweltrecht*, 2, p. 105 ff.

Ryll, A. & Schäfer, D. (1988) 'Satellitensystem "Umwelt"', in: Reich, U.-P. & Stahmer, C. *et al.*, *Satellitensysteme zu den Volkswirtschaftlichen Gesamtrechnungen*, Forum der Bundesstatistik, Volume 6 (Mainz and Stuttgart, Federal Statistical Office).

Schäfer, D. (1986) 'Anlagevermögen für Umweltschutz', *Wirtschaft und Statistik*, 3, p. 214 ff.

Schäfer, D. (1988) 'Umweltschutzleistungen der Entsorgungsunternehmen und des Staates', in: Reich, U.-P. & Stahmer, C. *et al.*, *Satellitensysteme zu den Volkswirtschaftlichen Gesamtrechnungen, Forum der Bundesstatistik*, Volume 6 (Mainz and Stuttgart, Federal Statistical Office).

Stahmer, C. (1986) 'Integration der Input-Output-Rechnung in die internationalen Systeme Volkswirtschaftlicher Gesamtrechnungen', in: Reich, U.-P. & Stahmer, C. *et al.*, *Internationale Systeme Volkswirtschaftlicher Gesamtrechnungen, Forum der Bundesstatistik*, Volume 4 (Stuttgart and Mainz, Federal Statistical Office), p. 92 ff.

Stahmer, C. (1987) 'Umweltberichterstattung im Rahmen der Volkswirtschaftlichen Gesamtrechnungen', in: Federal Statistical Office, ed., *Statistische Umweltberichterstattung, Forum der Bundesstatistik*, Volume 7 (Stuttgart and Mainz).

Statistical Office of the European Communities (1979) *European System of National Accounts (ESA)*, 2nd Edition (Luxembourg).

United Nations (1975) Draft Classification of Outlays of Industries by Purpose (COIP), ST/ESA/STAT/83, 11 August 1975.

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Input–Output Analysis: The First Fifty Years

ADAM ROSE & WILLIAM MIERNYK

'Input–output economics is that rara avis *in economics, a genuinely new and original idea. It was not without precursors and Leontief has always been at least adequately generous in acknowleding them.... The fundamental discovery that distinguished Leontief's work from that of all his predecessors is that it was practical to calculate the input–output coefficients from recorded data, to perform the necessary algebraic manipulations, and to use the results to answer a wide variety of practical economic questions' (Dorfman, 1973; pp. 430–31).*

1. Introduction

It has been a half-century since Wassily Leontief published his article on 'Quantitative input–output relations in the economic system of the United States' (*Review of Economic[s and] Statistics*, August 1936). This was the beginning of what has become a major branch of quantitative economics.

Conditions for launching a radical new method of economic analysis were far from auspicious. Keynes had just published *The General Theory*, and economists were heavily involved in Keynesian exegesis. There was, in addition, a heavy emphasis on policy as economists sought to understand the causes of, and prescribe a cure for, the Great Depression.

World War II did much to validate some of the Keynesian hypotheses, and it quickly eliminated the unemployment which had troubled economists for a decade. Many, however, were not convinced that the root causes of the depression had been extirpated. There was concern that when the war ended, large-scale unemployment would recur. This led a group of economists in the Bureau of Labor Statistics to consider how input–output (I–O) analysis might contribute to the goal of a full employment policy. Leontief served as an adviser to this group, and a series of articles on postwar employment prospects was one result of this study. Another result was the 1947 I–O tables—the first large-scale tables to be published. Beginning in 1958, additional tables have been constructed, at approximately five-year intervals, by the Bureau of Economic Analysis of the US Department of Commerce.

Interest in input–output analysis spread rapidly after World War II. Today, virtually all developed nations, and many developing countries, maintain sets of I–O accounts to complement their national income accounts. I–O is used in centrally-planned societies as well as those that profess to be guided by the dictates of the marketplace.

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NMED - ROSE
REBUTTAL EXHIBIT 1

One characteristic of the input–output model is its versatility. It is, for example, probably the most widely used method of regional analysis. Small-area I–O models, at the county or community levels, also have been constructed. A few interregional or multiregional models have been developed. At the other extreme, Leontief and several associates have constructed a global model in which blocs of countries are considered to be 'regions'.

Many early applications of the input–output method dealt with the broad area of economic development. The flexibility of the model made it ideally suited for both the simulation of economic development and, where data permitted, the construction of tables for the measurement of income and employment multipliers. In recent years, however, there has been growing concern among economists with the consequences of economic development. Environmental economics, a relatively new offshoot with close ties to ecology, has become an area of major interest. Also, since the 1970s, the system has been applied to a variety of energy and resource issues. Far from being an inflexible and limited model, as early critics implied, the I–O system has proved to be flexible and versatile.

Input–output practitioners are keenly aware of the difficulties involved in the empirical application of the model. It requires masses of data, and a major gap in the data-collection procedures of most nations is the failure to collect information on interindustry and interstate (or interregional) transactions. Practitioners have been forced to rely on expensive surveys or on a variety of 'short-cut' methods for estimating these transactions. The paucity of published statistics that lend themselves to I–O applications has no doubt retarded the growth of this field.

This review is organized into five major parts. We begin with a presentation of the basic I–O model and a discussion of the major assumptions upon which it is based. We then discuss some of the misconceptions about the model, including a discussion of how the fixed-coefficient assumption is not as restrictive as many critics have suggested. A large section of the paper presents the many conceptual extensions of the basic I–O model that have significantly broadened its scope. An even larger section is devoted to a discussion of the numerous areas of application of I–O models and the insights these applications have provided. The final major section of the paper focuses on data requirements and methods of construction for the numerous empirical I–O models at the national and regional levels.

2. The Basic Model

The static, open I–O model is based on a table of purchases and sales between sectors of an economy, or transactions table. This table can be expressed as a system of accounting identities:

$$X_i = X_{i1} + X_{i2} + \ldots + X_{in} + Y_i \; (i = 1 \ldots n) \quad (1)$$

where

X_i = total gross output of sector i,
Y_i = the autonomous final demand for the products of sector i,
X_{ij} = the sales by sector i to each of the endogenous sectors j.

Three assumptions enable equation (1) to be converted into a model capable of analysis and prediction. They are that: (a) each commodity or service is provided by a single production sector, and that there are no joint products; (b) each sector's inputs bear a direct proportional relationship to that sectors' output; and (c) there are no external economies or diseconomies.

Assumption (b) may be written as:

$$X_{ij} = a_{ij}X_j \quad (2)$$

Substituting (2) in equation (1) yields the basic I–O model:

$$X_i = \sum_{j=1}^{n} a_{ij}X_j + Y_i \; (i = 1 \ldots n) \quad (3)$$

The endogenous elements of (3) may be rewritten as:

$$a_{ij} = \frac{X_{ij}}{X_j} \quad (4)$$

the model's 'technical coefficients'.

The balance equation can also be written compactly in matrix notation as:

$$X = AX + Y \quad (5)$$

Solving for annual gross output needed to deliver that exogenously given set of final demands yields:

$$X = (I - A)^{-1}Y \quad (6)$$

This system is subject to two mathematical constraints. First, no column sum of the A matrix can be greater than unity and at least one column sum of the A matrix must be less than one; and, second, there may be no negative elements in the Leontief Inverse, $(I-A)^{-1}$. The latter is the major implication of the Hawkins-Simon (1949) condition. Since technical coefficients were computed for processing sectors only, and these sectors excluded such final payments as taxes, imports, and in the usual case, households, the first constraint posed no problem. A negative element in the Leontief inverse would mean that as a sector expanded its output, *ceteris paribus*, it would require fewer and fewer inputs. Thus if either of these two conditions are violated, either the equations have been improperly specified or there have been computational errors in obtaining the solution.

Even the basic version of the I–O model has many valuable and often unique attributes. These include a framework for the collection and organization of detailed data on economic activity, a detailed description of economic structure, a bottom-up determination of aggregates, a comprehensive means of assessing economic impacts (both primary and higher-order), and computational manageability. These and many other capabilities and relative advantages of the model will be illustrated by the discussion of extensions and applications of I–O in later sections.

3. Misconceptions

The major criticism of I–O concerns the fixed (structural) coefficients of production in the basic model.[1] As originally defined by Leontief (1941; p. 37) the term means that: 'the amount of each cost element is assumed to be strictly proportional to the quantity of output'. Leontief explained this formulation as justified by the limitations of 'available statistical data' and by observable fact, and noted that it was not as restrictive as it might appear. He pointed out that much of what passes for substitution of one input for another in empirical economic studies was simply due to the high level of aggregation used in early macroeconomic models and in neoclassical production functions of the entire economy based on two or three primary factors. The more disaggregated the model the less likely it is to confuse this 'technical substitution' with changes in the product mix. Leontief also suggested that production decisions were more reasonably considered in terms of a limited number of discrete activities, or entire production techniques. As such it would take wide swing in relative prices to effect a switch. Even for a single technique with some flexibility, a high degree of input complementarily would require a major swing in relative prices before substitution took place. Also, as Georgescu-Roegen (1950; p. 216) noted, 'although alternative processes may exist, only one is actually used and, therefore, only one can be statistically observed'.[2]

Aside from technical substitution, however, there is the problem of incorporating the more dynamic phenomenon of 'technological change', or the formulation of new methods of production.[3] Possibly because I–O coefficients for a given year are often used in analyses of situations several years forward or backward in time with no modification, it may seem that TC cannot be accommodated within I–O. However, it readily can be. In fact, since TC usually involves year-to-year changes, as opposed to more likely intra-year changes in cases of technical substitution, it is the more tractable of the two in terms of basic I–O computations. Still there is the potentially difficult problem of 'projecting' the changes in individual coefficients. Fortunately, there are a number of methods that can be used to analyse TC in an input–output framework. A brief summary follows.[4]

The first set of methods are limited short-term or *trend-line* approaches. The *ex ante* method (Fisher & Chilton, 1972) utilizes expert opinion in projecting coefficients, and in short-term applications represents the self-fulfilling prophecies of engineers and plant managers. This method has the advantage of utilizing information from those at the scene of production, but must often reconcile divergent views among experts about the more distant future. The extrapolation method (Miernyk *et al.*, 1970) uses descriptive statistics or stochastic analysis of time series data. In a disaggregated I–O context, its widespread application has been limited by lack of data. The heuristic approach also stops short of offering an explanation of the causation of coefficient changes, and uses simple correlation, analogy or metaphor. Examples are the application of national trends at the regional level (Tiebout, 1969) and the logistic adoption function (Almon *et al.*, 1974). Another rudimentary method might be termed the mechanical and includes wholesale updating techniques, such as the RAS method (Stone *et al.*, 1963). Many critics argue that these methods lack a sound economic basis and should only be used as a last resort, if at all (see, e.g., Lynch, 1986).

There are two short-cut *indexing* methods for dealing with TC. The first is referred to as cost-engineering, which involves the application of fundamental engineering relationships and principles (Chenery, 1953; and Isard *et al.*, 1959). Many of these principles, such as the 'fractional power law', can be applied to changes in the scale of operation on a year to year basis. Another method is the policy-cost index (Rose 1976), which translates a policy goal into a measurable scale and calculates the costs of different levels of attainment, typically from corresponding micro-level data.

A third set of methods is more *behavioural* in nature. The best-practice method (Carter, 1953; Miernyk, 1968) is based on the fact that at any point in time there are different vintages of production processes in place. The shift from all processes to the more productive new ones is essentially TC. In subsequent work, Carter (1963; 1970) offered two ways of determining the pace of adoption. The penetration/diffusion method (Ayres & Shapanka, 1976) combines elements of the theory of the adoption of innovation and the logistic function of the heuristic method to more comprehensively explain the pace in terms of price competition, obsolescence, and diffusion of innovation.

Another set of approaches involves more explicit *optimization*. This includes process analysis, which involves the consideration of a set of alternative techniques, but without ranking them as in the best-practice approach (Manne & Markowitz, 1962). The pseudo-data approach (Klein, 1974; Griffin, 1977) uses the least cost solutions of process analyses of different scale levels to provide the simulated data for the statistical estimation of a cost function. As in the case of process analysis, this approach has the advantage of utilizing engineering data to make up the deficiency of lack of time series data in cases of new technology. The production function approach (Hudson & Jorgenson, 1974), on the other hand, typically uses time series data, flexible functional forms, and the duality principle. It is even more well suited to cases of technical substitution in response to a change in relative prices.[5]

The extensive number of methods for projecting coefficient change means: first, that I–O does not deserve much of the criticism it receives for being a rigid tool of analysis, insensitive to price changes, policy regulations and innovation. Second, given the availability of numerous approaches to incorporate TC into I–O models, researchers no longer have a legitimate excuse for assuming away TC or using crude modification methods.

4. Extensions

Soon after offering I–O as a means of tabulating and analysing the basic interrelationships of production, Leontief (1937) showed how the model could be extended to analyse price formation. This was just the beginning of scores of contributions by Leontief and others to broaden the capabilities of the model. Today, I–O models can readily incorporate pricing, dynamic, and socioeconomic aspects, and, when combined with other model forms, can be used for such purposes as forecasting and planning.

4.1. Dynamic Models

The static I–O model emphasizes the interdependencies within the economy during a given period. It focuses on annual flows and treats the carryover of stocks or their use in production only implicitly. In 1953, Leontief published a dynamic version of his basic model—one in which time is incorporated explicitly. The formulation was able to make investment activity endogenous to the system. In subsequent work the embodiment of technological change in this investment implicitly or explicitly served as a basis for alterations in current input coefficients in dynamic models.

The most general form of an operational dynamic model is given by the following balance equation:

$$X_t - A_t X_t - D_t X_t - B_t(X_t - X_{t-1}) = Y_t \qquad (7)$$

where

X_t = a vector of total gross output by sector at time t,
A_t = a matrix of direct input requirements per dollar of output at time t,
D_t = a matrix of *replacement* capital coefficients,
B_t = a matrix of *expansion* capital coefficients, and
Y_t = a vector of final demand by sector at time t.

The key element of the model is the general concept of a capital coefficient—a fixed per unit requirement of capital needed to produce an additional unit of capacity. This is the main component of the accelerator investment equation, which calls for capital stock changes in direct proportion to output capacity over time.[6] The model is thus dynamic from an economic standpoint in that production in one period is dependent on that of another period, and dynamic in a mathematical sense in that the model is formulated as a set of difference equations.

There are several solution approaches to the dynamic model (see, e.g., Miller & Blair, 1985).[7] The most general involves a simultaneous equation solution and a construct known as the dynamic inverse (Leontief, 1970b), which shows how an exogenous change in the final demand for a good stimulates direct and second-order demands in several previous time periods.

4.1.1. Controversies. Leontief's original dynamic model led to a debate with J. D. Sargan (1958), who argued that the model was inherently unstable after examining the behaviour of the model in three special cases. Leontief (1961; p. 668) countered with examples that showed 'well behaved dynamically stable linear models with technological or behavioral lags can indeed be easily constructed'.

Another controversy surrounded the characterization by Dorfman, Samuelson & Solow (1959) of the dynamic I–O model as a special case of the von Neumann growth model. They revealed some instabilities when one assumes full capacity utilization. However, Solow (1959) also showed how the problem could readily be eliminated. Still, one of the problems with the accelerator investment model within the I–O framework deals with the implication of an economic contraction. Expressed either in terms of gross output or capacity utilization, a decline in these independent variables implies disinvestment. This poses no problem in a 'putty-putty' world where capital in place can be transferred across sectors, but is cause for concern in real world applications. More recently, Duchin & Szyld (1986) have developed a version of the model that guards against such problems by reformulating it to include lead-time requirements.

Another concern with the existence[8] of a meaningful solution to the dynamic I–O model stems from interpreting it as a dynamic growth model. Until recently, a balanced growth solution was shown to be possible only under certain strong restrictions on the *A* and *B* matrices. However, Szyld (1985) has shown that a solution exists under conditions likely to be found in most advanced economies.

4.1.2. Empirical Models. The strongest support for the dynamic I-O model was the stable versions of early empirical models constructed by Almon (1966), Emerson (1969), Leontief (1970b), Miernyk *et al.* (1970), Bourque (1970), and others. The lag structures of the systems of difference equations in these models accurately reflect the differences in gestation periods of specific additions to the stock of capital as the latter expands.[9] This no doubt helps explain the stability of operational models.

The dynamic I–O model has been applied to several important issues. Some of these will be discussed in the context of economic development applications. Other applications include the work of Carter (1974) on the effects of environmental regulations on the long-run growth of the US economy, and the work of Leontief & Duchin (1986) on the economic impacts of automation in the USA.

Dynamic I–O models are more versatile than their static counterparts. However, as

Bulmer-Thomas (1982) has pointed out, useful dynamic models can be developed only for economies that produce a significant volume of capital goods. Thus, for industrialized regions and developed nations, dynamic models have the potential for becoming powerful analytical tools. Still much work remains to be done on the collection and processing of detailed data on capital stock.

4.2. Prices

The basic I–O balance, presented in equation (1), represents a full accounting of commodity flows, and equation (3) provides a way of determining equilibrium gross output. There is, however, no explicit mention of prices. This contrasts with neoclassical partial and general equilibrium models, which compute prices and quantities simultaneously. The input–output approach to calculating prices is based on the same technical coefficients that are used to calculate quantities. That prices and outputs can be computed separately is attributable to the special assumptions of the basic I–O model: perfectly elastic supply functions and perfectly inelastic demand functions, consequences of the assumption of fixed input proportions. Where these assumptions have been viewed as overly restrictive, the model has been successfully refined to incorporate output responsiveness to prices and vice versa.

4.2.1. Conceptual Framework. Analogous to the quantity version of I–O, the price counterpart is based on an identity: the price of a good is equal to the cost of intermediate goods plus the value of primary factors involved directly in its production. In matrix notation this price model is:

$$P = A'P + V \tag{8}$$

and is solved as:

$$P = (I - A')^{-1}V \tag{9}$$

where

P = a vector of commodity prices,
A' = the transpose of the matrix of technical coefficients defined above, and
V = a vector of value-added.[10]

Equation system (8) can be solved in either open or closed form, though in the latter case only in terms of relative prices. The open model involves n equations (sectors) and $n+1$ variables (n commodity prices + value added). In the closed model, all prices are computed endogenously, though as is typically the case for a set of linear homogeneous equations, there is an infinite number of solutions. What the solution does yield, however, is a unique proportionality relationship between all prices, i.e., as in a standard Walrasian formulation, it allows at least for the calculation of relative prices.

The solution system (9) provides insights into the overall composition of prices. Elements of the transposed inverse yield information on the direct, indirect, and induced effects of the price of one commodity on another price, analogous to the multiplier effects of the quantity-balance counterpart. Changes in value-added transmit their effects through successive rounds of 'cost-push' inflation, with the overall price impact throughout the economy being several times the direct impact. Explorations into a dynamic I–O price model have been undertaken by Solow (1959), Leontief (1970b, 1986), Haig & Wood (1976), and Duchin (1980).

4.2.2. Complications of 'Value-Based' I–O Tables. Most empirical I–O tables are not constructed in terms of physical quantity units (e.g., tons, barrels, passenger miles), nor are individual commodity prices calculated. Instead, the convention has been to tabulate expenditure values. The approach has the advantage of translating the entries in a table into a common denominator of monetary units, which facilitates checking accounting balances and intersectoral comparisons of input intensities. However, it leads to three complications.

The first involves the price balance equation (8), which has to be reinterpreted in unit value terms. That is, since the technical coefficients are all expressed on a 'per dollar' basis, the 'price' of each commodity is equal to unity! As such, the price is an index number for each sector in one interpretation of the model. This poses less of a problem than it may seem, since base year prices can be calculated separately from the I–O model or may be readily available in a statistical series. Also, for impact studies, knowledge of price changes may be sufficient.

The second complication arises from the fact that each technical coefficient, z_{ij}, calculated from a value-based table is equal to the corresponding coefficient of the physical quantities table, a_{ij}, *multiplied by the ratio of input and output prices*, P_i and P_j, respectively, i.e.,

$$z_{ij} = a_{ij}\frac{P_i}{P_j} \tag{10}$$

Moses (1974) has pointed out that many of the studies of the stability of empirical input–output coefficients are couched in terms of technical stability and neglect the presence of relative price terms, which can have either a stabilizing effect (as when they offset technical change) or a destabilizing effect.

4.2.3. Applications. The static price model has been used for empirical work in different contexts. These include analyses by Leontief (1947) on the basic price structure of the US economy. Leontief (1970a) also provided the seminal article on the effects of environmental regulation on prices. A key issue posed in the paper is that while these regulations may raise the price of producing goods and services, they need not represent a decrease in economic welfare if the non-market value of a cleaner environment is considered. Applications of the price model to pollution control have been made by Giarratani (1974) at the regional level, and by Yan *et al.* (1975) at the national level to examine consumption pattern effects. Analogous applications for the effects of higher energy prices have been done by Miernyk *et al.* (1977).

Catsambas (1982) has examined the economy-wide price increases caused by the imposition of a gasoline tax, i.e., the forward shifting of the tax. I–O is ideally suited for this purpose since it represents the general equilibrium framework many experts believe is necessary for an accurate analysis of tax incidence (Augustinovics, 1989; Pleskovic, 1989). A comprehensive study of the price effects of the corporate income tax and its potential effects on the terms of trade between the USA and Canada by Melvin (1982) raises an important issue. I–O studies of this type are only as good as the empirical estimates of price mark-ups. Many studies have made use of 100% mark-ups not only because of lack of data, but for computational convenience. Use of mark-ups less than unity requires further refinements of the model.

4.3. Extended I–O Models and Social Accounting Matrices

4.3.1. Extended I–O Models. The work on 'extended' I–O models deals with the incorporation of socioeconomic variables, most typically through disaggregations or other modification of the income payment or consumption expenditure quadrants. For example, the literature on the explicit role of migration dates back to the work of Miernyk *et al.* (1967) and Tiebout (1969), who suggested that the consumption stimulus from in-migrants to a region should be based on average propensities to consume, while a consumption stimulus from prior residents should be represented by marginal propensities, due, for example, to the pecuniary externality of rising wages. More elaborate models of locational attractiveness have been formulated (see, e.g., Ledent, 1978).

Early I–O models implicitly attributed zero income levels to the unemployed. Later models explicitly included taxes and transfer payments in impact calculations. These range from specific models dealing with the role of unemployment compensation by Oosterhaven (1983) and Batey, Madden & Weeks (1987) to the more general treatment by Golladay & Haveman (1976).

Another extension added occupation and skill level variables. The sectoral disaggregation of an I–O table lends itself to further disaggregation of the occupational composition of each production process. The resulting 'industry/occupation', or manpower, matrices typically embody the fixed input requirement assumption of conventional I–O coefficients. Therefore, if pre-multiplied by a vector of gross output changes, this construct yields an estimate of increased employment opportunities in a highly detailed form. These matrices have been compiled for a number of years at the national level (see, e.g., US BLS, 1982), but were relatively rare at the regional level (see, however, Miernyk *et al.*, 1970) until more recent work by the US Department of Commerce (1984). Freeman (1980) has found the manpower coefficients for the USA to be relatively stable over time, despite productivity changes (see, e.g., Wolff & Howell, 1989). More complete labour market considerations have more recently been incorporated into I–O models as well (see Oosterhaven & Folmer, 1985).

Other extensions involve disaggregation of standard aspects of the I–O model such as the disaggregation of consumption and payments by income bracket. The disaggregation of personal expenditures is based on well documented differences in consumption propensities among various groups, and is intended to improve the accuracy of estimated of spending impacts. The disaggregation of the payments sector provides a link between production and disaggregated consumption, but can also be used to evaluate the income distribution impact as an end in itself.

The most general formulation of the disaggregated extended model is that of Miyazawa (1976):

$$X = AX + CVX + \bar{Y}, \tag{11}$$

where A and X are defined as above and

C = an $n \times r$ matrix of consumption coefficients, c_{ik}, by commodity i and income class k,
V = an $r \times n$ matrix of income distribution coefficients, v_{kj}, by income class k and sector j, and
$\bar{Y}$ = other final demand.

The solution to equation (11) is:

$$X = (I - A - CV)^{-1}\bar{Y} \tag{12}$$

$$= B(I-CVB)^{-1}\bar{Y} \quad (13)$$

where $B = (I-A)^{-1}$

If we set $K = (I-VBC)^{-1}$ and substitute into (13), we obtain:

$$X = B(I+CKVB)\bar{Y}. \quad (14)$$

The major contributions of this model stem from the *decomposition* of income generation and distribution processes. From this formulation Miyazawa has defined an income generation multiplier, *KVB*, which shows how an additional unit of total income affects income in each bracket; and an interrelational multiplier, *VBC*, which shows how much income is generated for one income bracket through direct, indirect and induced effects of a unit increase in income in another bracket.[11]

4.3.2. SAMs. A Social Accounting Matrix (SAM) is a set of accounts depicting the interaction among various components of the socioeconomic system. The formalization of this concept is attributable to Richard Stone (1961a), as an outgrowth of his work on national income accounting.

Stone (1977) points out that the SAM has 'two distinct aspects': the 'taxonomic' and the 'analytical'. These, of course, are the two main features of the I–O model as well. The SAM can be thought of as an extension of the basic I–O model's focus on producer–producer relations to the broader realm of institutions, defined by Pyatt *et al.* (1977), in this context, as 'entities having the legal right of ownership and hence being able to accumulate and to provide services'. On the other hand, one can view the SAM as a more general framework with I–O as a special case, especially when it is taken to include non-linear formats, e.g., computable general equilibrium models. However, it is clear that SAMs have benefitted from decades of research on I–O models, ranging from data collection to the matrix methods used in the solution of both types of models. Otherwise, the important differences between the SAM and the I–O model are that the former allows for the use of socioeconomic accounts rather than monetary or physical volume units, and it also places an emphasis on the 'balance sheet' as opposed to the 'income statement' basis of the static version of the I–O model.

The basic SAM format contains four components: production, income/consumption, accumulation, and trade. The simple version also nets out intra-component transactions, which results in zero-valued elements on its diagonal, thus omitting the major intra-industry production relationships given in the I–O model.

The scope of SAMs has expanded in recent years as data collection and modeling improvements have increased. An example is the work of Pyatt *et al.* (1977), in which the institution current accounts have been divided into the subcategories of firms, households, and government. These were further disaggregated to account for transactions within and among sectors. Moreover, the income/consumption category is separated. In fact the authors perform a type of socioeconomic income distribution analysis by further dividing factor payments according to those flowing to urban, rural, and estate households. Still other extensions of SAMs have been suggested to incorporate flow of funds variables through a disaggregation of financial sectors (see, e.g., Greenfield, 1985).

4.3.3. Model Construction and Application.[12] Several of the income distribution variants of extended I–O models and SAMs have been applied to growth and development (see, e.g., Chenery *et al.*, 1974; Adelman & Robinson, 1978). A major application of the extended model to other areas is the study of the effects of the negative income tax

on the size distribution of personal income by Golladay & Haveman (1976). They found that, after direct and indirect repercussions were taken into account, the middle income, and to some extent the higher income classes, benefited most. This stemmed from the direct shift in increased spending among lower-income groups favouring goods demanding higher skills and thus higher wages. A study by Henry & Martin (1984) found that a redistribution in favour of lower income groups resulted in an overall higher level of regional income because of the groups' relatively smaller savings propensities. Of course, omission of dynamic savings–investment relationships may have seriously biased the results.

A major shortcoming of the Golladay & Haveman study was its confinement to wages and salaries, due to the lack of primary data for the multisectoral distribution of other income types (e.g., interest, dividends, rents, etc.). This problem has been overcome recently by Rose *et al.* (1988), with the aid of survey and published primary data, in constructing a multisectoral income distribution matrix for the USA and several of its regions. Coupled with empirical work on income differentiated consumption, Rose & Beaumont (1988) have calculated the first set of empirical Miyazawa interrelational multipliers, at the regional level (see also Grootaert, 1983).

In addition to the examples presented earlier, SAMs have been constructed primarily for LDCs by, among others, Eckaus *et al.* (1981), Bulmer-Thomas (1979), and Bell *et al.* (1982). Major efforts, sponsored by the US Forest Service and US Department of Agriculture, are being undertaken to develop a general SAM modeling capability for the USA and its regions (see Despotakis, 1985; Robinson *et al.*, 1988). More specialized SAMs have been constructed such as one based on the flow of funds between financial institutions and economic sectors (see Greenfield, 1985).

Overall the distinction between I–O models and SAMs is not clear-cut. From the discussion above there are clearly many areas of overlap. The major differences are really those of emphasis and perspective. The basic I–O model places an emphasis on interactions among producers and the mix of output, while SAMs place an emphasis on the interaction among institutions and the distribution of income and other flows. Extended I–O models have clearly helped close this gap, while many SAMs have been constructed with full-blown I–O tables embedded in them.[13]

4.3.4. Multiplier Decomposition Analysis. A major methodological innovation that has recently sparked renewed interest in relation to extended I–O models and SAMs is called *multiplier decomposition analysis*. It refers to the disaggregation of more complex I–O interdependencies into separate constituent elements as in equation (14) above. More sophisticated analyses are based on partitioning properties of matrices and their inverses (see, also, Miyazawa, 1976), and are similar to the approach first utilized by Miller (1966) in the context of interregional direct and feedback effects.

In the case of extended I–O models, various decompositions have been undertaken (see Batey, 1985, for an excellent taxonomy and comparison of relative multiplier size). In the context of SAMs, matrix decomposition has provided additional insight into the interaction between institutions (see, e.g., Pyatt & Round, 1979; Stone, 1985). More recent advances in this field are summarized in a new contribution by Pyatt (1988). A comparison of conventional and flexible-price SAM multipliers has also been undertaken by Robinson & Roland-Holst (1988).

4.4. The Supply-side or Allocation Model

An interesting variant of the standard I–O model was developed by Ghosh (1958). Its three major distinguishing features are: (1) fixed coefficients based on the distribution of product sales across sectors; (2) impacts generated by exogenous changes in primary factors as they run their course throughout the economy; and (3) perfectly elastic final demand. These features can be stated more precisely in terms of 'supply-side' balance equations. First define an allocation coefficient, s_{ij}, as an input flow expressed in terms of a row, rather than a column, sum of expression (4) above, thus:

$$s_{ij} = \frac{X_{ij}}{X_i} \tag{15}$$

In matrix notation, gross output levels can now be expressed as:

$$X = SX + V \tag{16}$$

with the solution equation being:

$$X = V(I-S)^{-1} \tag{17}$$

4.4.1. Conceptual Basis. Ghosh suggested that fixed 'allocation' (sales distribution) functions would be appropriate to cases of 'an economy where different sectors are under monopoly control and all except one factor is scarce'. That is best exemplified by a centrally planned economy, but a market economy might fit the description either when it operates by decree, as in a national emergency, or by voluntary action, as in the case of a seller rationing the short supply of a good among his customers. Ghosh notes that under these circumstances one cannot expect the usual stability of the corresponding input coefficients.

A number of important criticisms have been leveled at this formulation of the supply-side model. Giarratani (1980) has pointed out that its conceptual base has not been explained in terms of any well conceived behavioral process. Chen & Rose (1986) have raised concerns about the implicit instability of the underlying production relations. Does Ghosh's disclaimer regarding stability mean we should tolerate any possible, or even technically impossible, rearrangement of inputs? Fortunately, Chen & Rose (1986) discovered an inherent 'joint stability' between production and allocation coefficients, though it cannot be ascribed to well founded behavioural considerations.[14] Finally, Oosterhaven (1981; 1988) has questioned the general plausibility of the allocation model, and has provided useful guidelines for applying it in the limited number of cases he deems appropriate.

Some of the pressure on the allocation model can be removed if it is generalized or extended, or simply if the restrictiveness of its basic assumptions are relaxed. Recently, Cronin (1984) pointed out that the two distinguishing features of the model need not be utilized in tandem to perform meaningful economic analyses. In the schematic below we can see the Ghosh and Leontief versions as two polar forms on the dimensions of analytical assumptions and causal ordering. There are two hybrids, which Cronin suggests might prove useful in situations such as: (A) a shortfall of energy under conditions of limited substitution; and (B) demand shifts in centrally planned economies.

	Causal Ordering	
Analytical Assumptions	Demand	Supply
Production Function	Leontief	Hybrid A
Allocation Function	Hybrid B	Ghosh

4.4.2. Empirical Models. One positive attribute of the allocation model is that it is easy to derive from an existing transactions table. Also, just as in its conventional counterpart, multipliers can be calculated for the allocation model. The supply output multipliers, for example, defined as the *row* sums of $(I-S)^{-1}$ of equation (17), reveal the direct, indirect and induced stimulus throughout the economy from a one unit change in a primary input in a given sector. The calculation of Ghoshian output multipliers for the 1967 US I–O Table by Cronin (1984) indicates they differ significantly from their standard counterparts.

An analysis of the stability of allocation and production coefficients by Giarratani (1980) revealed some remarkable similarities between the two in terms of both direct requirements and total requirements matrices for the USA between 1963 and 1967. The analysis was extended to examining per cent changes in both types of multipliers, again finding neither version more stable than the other. Similar results were found for various European countries by Augustinovics (1970). It should be kept in mind, however, that many of the supply-side model's applications call for much more significant perturbations than those found over these short time spans.

4.4.3. Applications. Most subsequent applications of the supply-side model have been to market economies, but under conditions of serious resource shortage. The first major empirical study using the model (Giarratani, 1976) focused on the economy-wide output implications of changes in petroleum production in the USA. More recent examples include the study of Davis & Salkin (1984) of the effects of a shortage of water on an agricultural region in California.

Two major extensions of the allocation model appear promising. The first uses this framework as the basis of multi-regional I–O models (see Bon, 1984). These models have for some time contained some element of fixed trade patterns (see, e.g., Polenske, 1966), but Bon's formulation facilitates an extension to the entirety of transactions if desired. Also, after many years of using production coefficients, economists are now approaching a consensus that allocation coefficients are the preferred basis for computing 'forward linkages' used in economic development studies to analyse the effects of a supply stimulus (see section 5 below).

4.5. Input–Output and Related Methods

Leontief (1936; p. 105) readily acknowledged the historical roots of I–O when he stated that: 'The statistical study presented in the following pages may be best defined as an attempt to construct, on the basis of available statistical materials, a *Tableau Economique* of the United States for 1919 and 1929.' Elsewhere, Leontief (1941) makes reference to similarities between I–O and the original (fixed coefficients) versions of the Walrasian general equilibrium model.

Other links have been explored over the years including consideration of I–O: as a special case of activity analysis that is usually solved by a linear programming algorithm (Chenery & Clark, 1959); in comparison with the Soviet 'materials balance' planning technique (Levine, 1962); in comparison with Sraffa's classical system (Samuelson, 1971); association with neo-Marxist static and dynamic formulations (Brody, 1970; Morishima, 1973); as the basis for multi-sector growth models (Tsukui, 1972); as a *de facto* econometric model (Gerking, 1976); and as the empirical base of most computable general equilibrium models (Shoven & Whalley, 1984). Space does not permit the elaboration of each of these connections, so we will consider only three below.

We begin with the connection between I–O and linear programming (LP). Both of these are subsets of activity analysis, an approach that divides a system into a set of linear homogeneous relations between inputs and outputs (activities). Activity analysis is a general formulation that encompasses the possibility of having several activities produce a single output and a given activity producing multiple outputs. Thus, I–O is essentially a special case that establishes a one-to-one correspondence between production techniques and products.[15] The I–O system can be solved by ordinary simultaneous equation methods; however, the more complex activity analysis problem cannot. Linear programming represents the most popular solution algorithm for the more general case. Moreover, LP provides an explicit mechanism of choice and a formal optimization procedure.

I–O/LP models have been combined in three major ways. The first, following Chenery & Clark (1959), calls for a type of planning formulation that incorporates an objective such as the maximization of GNP subject to primary factor constraints and solves for levels of gross output among producing sectors and 'slack' sectors. Another formulation by Chenery & Clark, 1953 (see also Carter, 1970; Kohn, 1971) chooses both activities and activity levels. This has been generalized to some sophisticated multisector development planning models to be discussed below (see, e.g., Bruno *et al.*, 1970; Manne, 1974; and Dervis *et al.*, 1983). Finally LP is often linked to I–O as a submodel, or side-calculation, to adjust some subset (see e.g., Rose 1976) or the entirety of the coefficients (see, e.g., Davis *et al.*, 1978; and Leontief, 1986).

The connection between I–O and econometric models has gained increasing attention over the past dozen years. I–O is sometimes applied to forecasting, but by itself is hardly a forecasting model. The I–O model needs something to 'drive' it if it is to be used to project output for future years. This typically involves the use of exogenous forecasts of final demand elements. Almon has pioneered this field (see, e.g., Almon *et al.*, 1974; and Almon, 1984), and developed one of the most widely used I–O forecasting models in existence today—the INFORUM (Interindustry Forecasting at the University of Maryland) model. The model includes many other valuable features including dynamic elements relating to investment and coefficient change.

The combining of an I–O model and an econometric model dates back to the Brookings Quarterly Forecasting Model (Fisher *et al.*, 1965), and is now a part of most large scale econometric models for the USA. The I–O component complements the emphasis of the econometric models on aggregate demand and income with a detailed accounting of interindustry, or derived, demand and output. It also provides a more systematic way of tracing impacts through an economy. More recent work by Stevens *et al.* (1981) has 'conjoined' the two model components at the regional level.

Another approach to the subject is exemplified by the work of Hudson & Jorgenson (1974), who demonstrated that an integration of econometric and I–O models, as opposed to just a combination, was an operational possibility. They showed how the input coefficients of the I–O component could be made interactive with core elements (e.g., prices) of the econometric component.

A final I–O/econometric link has been formulated by Gerking (1976). In effect, he has offered a novel perspective on the subject by suggesting that a basic I–O model itself might be considered an econometric model. I–O models based on sample surveys definitely have stochastic properties. Gerking attempts to evaluate the reliability of tables by calculating measures of dispersion. He notes that the conventional way of tabulating I–O tables amounts to using a 'ratio estimator', and that two-stage least squares estimators have more desirable statistical properties.[16]

Finally, we note the connection between I–O and 'computable', or 'applied', general equilibrium models (CGE). Both models claim Walrasian roots, but the CGE model is closer to the later Walrasian tradition of non-linear supply functions, and the general neoclassical proposition of a multitude of individual decision makers on both the demand and supply sides. These microsimulation models date back to the work of Orcutt *et al.*, (1963) and Scarf (1967), and have reached a high level of empirical and computational sophistication.

The CGE appears to have many of the advantages of an I–O model: sectoral detail, consideration of intermediate production, etc. It also has what some see as distinct advantages: demand side detail, non-linear relationships, and responsiveness to prices (see, e.g., Shoven & Whalley, 1984).[17] Others would argue that these are not advantages at all (see, e.g., Leontief 1985) and that technological considerations, inherent linearities and non-responsiveness to prices dominate. To this we can add other disadvantages, such as the fact that no CGE models have been based on a consistent set of data with the exception of recent work by Jorgenson (1985). The empirical formulation of a given CGE model has typically called for borrowing key parameters, and from diverse sources.

Overall, CGE models have gained significant acceptance in the profession. However, these models and I–O should not be viewed as competitors, but as complements to each other (see, e.g., Robinson & Roland-Holst, 1988).[18] The issue is not which is superior, but which is most appropriate in a given context.

5. Applications

Applications of I–O can be categorized in at least two useful ways: by method and topic area. We utilize both approaches to further highlight the versatility of this tool of analysis. We continue to be selective and will emphasize methods where I–O studies have been in the vanguard (e.g., structural change, and policy analysis) and major topical areas (e.g., energy, and the impacts of technology).

5.1. General Economic Analysis

We will consider here the use of I–O for hypothesis testing, policy analysis, and economic planning. The first of these purposes involves the use of a storehouse of data to test important theoretical propositions. Perhaps the best known example is Leontief's (1953b; 1956) examination of the implications of the Heckscher-Ohlin theorem of international trade, which states that a country's comparative advantage, and hence specialization in exports, is based on relative factor endowments. The implications are that the USA would export relatively capital-intensive goods (given its highly developed industrial structure) and import labour-intensive goods (given the relatively cheap labour of its international competitors). Leontief, who measured both direct *and* indirect factor intensities, found just the opposite for the USA, a result referred to as the 'Leontief Paradox'.[19]

Leontief's paper stimulated a wide-ranging controversy involving economists in the USA and abroad. The policy implications of Leontief's foray into the domain of international trade were as unorthodox as were his analytical findings. It was (and still is) not unusual for trade union leaders to ally themselves with management to seek protection from foreign competition. Leontief (1953b; p. 349) argued, however, that 'protectionist policies are bound to weaken the bargaining position of American labor and correspondingly strengthen that of the owners of capital'.

Applications of I–O to policy analysis have been extensive. Again, I–O appears to be a 'natural' for such uses. Its advantages lie in the empirical content of I–O tables, the general equilibrium nature of I–O computations, and explicit recognition of the role of intermediate sectors.

A major area of I–O policy application has been to the economic impacts of reduced military spending. A first study by Leontief and several associates (1965) looked at the sectoral and regional distribution of those impacts. A more recent study by Leontief & Duchin (1982) examined the prospects on a global scale. The findings in both cases were that a shift from military to civilian production would result in an increase of economic output, though of course there would be some geographic dislocations. One useful finding of the studies relates to the identification of bottlenecks in the sectoral transitions involved. In addition, a novel idea proposed by Leontief & Duchin is the use of I–O data to aid in verification of arms agreements; that is, analyses of production levels of key supplies to defence industries can serve as a cross-check for, or in lieu of, on-site inspections.[20]

In general, I–O can be used in conjunction with other methodological approaches to policy analysis, such as scenario modeling, simulation, and optimization. In many cases the immediate concern is with the economic impact and not necessarily with the complete chain of causation. In these instances, analysts often resort to the use of sectoral I–O multipliers which can be calculated for a host of economic indicators including output (sales), income, employment, value-added, and prices (see, e.g., Miller & Blair, 1985). For example, each sectoral output multiplier represents the total (direct plus secondary) impact on gross output throughout the economy of a unit change in final demand for that sector.[21] These multipliers are simply calculated as the column sums of the Leontief inverse (see equation (6) above). Also, multipliers are often used as a short-cut to the calculation of impacts since they are assumed to be invariant to scale over a small range. Once multipliers are calculated there is no need to utilize the entire inverse until some significant technological change has taken place.

Again, one of the comparative advantages of I–O is in the calculation of general equilibrium effects. This has enabled the usually narrow area of project appraisal to be extended to one of policy analysis, where the broader implications can be observed (see, e.g., Tinbergen, 1966; Haveman & Krutilla, 1968; Haring & Daventer, 1976; and Oosterhaven, 1983). For example, resources can be valued more properly in terms of their opportunity costs, and benefits can include secondary effects where appropriate.

Another application of I–O is in economic planning. Here I–O can serve as a substitute for the information that might otherwise be provided by the market, or it can provide some insight into the consistency of future outcomes in a market system. The technical information embodied in an I–O table is immense, and, if an actual economy conforms to the basic linearity assumption, adjustments emanating from sectoral expansions and contractions can readily be determined.

Planning applications of I–O are extensive (see, e.g., Stone, 1981; Dervis *et al.*, 1982). Many development planning models, to be discussed in one of the following sections, involve formal optimization, but two major applications do not. The first is the use of I–O in the USSR. Given the centrally planned nature of the Soviet economy, and its former emphasis on material balances, I–O was ideally suited to the task of projecting detailed inputs to achieve exogenously determined gross output by sector.[22] Materials were allocated by trial and error for many years before the first I–O table for the USSR was constructed in the early 1960s (Treml, 1964). The solution to this production problem differs somewhat from that given by equation (6). Rather than taking final demand as given and solving for the necessary total output require-

ments, the Soviet solution sets gross output targets and solves for final demand largely as a residual (see, e.g., Levine, 1962). Thus shortages of consumer goods still arise in a country with a comprehensive and detailed planning system. A very different example of the use of I–O is the approach of indicative planning, best exemplified by the French experience (see, e.g., Courbis, 1979). Indicative planning refers to the process of disseminating detailed information on production requirements to avoid disequilibria, and to help make a projected outcome a self-fulfilling prophecy in an otherwise free market context.

5.2. Structural and Technological Change

The terms 'structural' and 'technological' change overlap to some extent in the I–O literature, in part because of the characterization of I–O parameters as 'technical coefficients'. The best resolution of ambiguity induced by this term is owed to Anne Carter (1970), who refers to technological change as the replacement of one production process by another. Structural change is more general. It refers to changes in input requirements, new products, and changes in the relative size of sectors within an economy. I–O is particularly well suited to the analysis of structural change given its disaggregated nature and its attention to intermediate inputs as well as primary factors of production.

5.2.1. Structural Comparisons. I–O has been used extensively to make cross-sectional comparisons among economies. Leontief (1963) has referred to four major concepts of structural analysis: interdependence, dependence, hierarchy and circularity. The first two refer to the extent to which an economy is composed of enclaves or of interrelated industries. Hierarchy refers to the economic pattern of primary, secondary and tertiary production, and their detailed components. Circularity, or roundaboutness, refers to the extent of intermediate good requirements for production.

Cross-country studies by Chenery & Watanabe (1958), and Simpson & Tsukui (1965) revealed similar structural patterns for countries at similar stages of development. This reinforced the idea that there is a distinct development pattern. In fact, Leontief (1963; p. 159) remarked that an 'economy can now be defined as underdeveloped to the extent that it lacks the working parts of the system'. While this analysis provides some insight into historical trends, the trend in development economics has moved away from 'emulation' approaches and has become more sensitive to the socioeconomic as well as the technological aspects of the problem. Overall, comparative structural analysis helps bring the big picture into focus, but has been of limited use beyond identifying basic qualitative features. It is hampered by aggregation and classification problems, and attempts at quantitative precision have not progressed beyond *ad hoc* judgements (see, e.g., Yan & Ames, 1965).

5.2.2. Structural Decomposition Analysis. The comparison of changes in structure in an economy over time lends itself to more rigour than static structural assessments and cross-country comparisons.[23] A methodology has evolved for this purpose, which might be termed 'structural decomposition analysis', or SDA.[24] Research in this area dates to the work of Chenery *et al.* (1962) and Leontief (1963), but was not presented in detail until the work of Skolka (1977). SDA represents a way of distinguishing major sources of change in an economy. It basically involves a set of comparative static exercises in which sets of coefficients are changed, in turn, and activity levels compared to a reference point.

Recent work by Rose & Chen (1988) has extended SDA to a level of detail and analytical capability equivalent to a two-tier KLEM model. This means the model is able to identify 11 types of response that correspond to the various parametric changes and substitution possibilities (both over time) in an aggregate production function composed of capital, labour, energy, and material aggregates, as well as energy and material subaggregates. Examples include material substitution, technological change in energy (energy conservation), and output effects. More recently Ohnishi & Kanemitsu (1989) have advanced SDA in the course of examining structural change in Japan, with a special emphasis on the role of international trade (see also the application of the methodology by Skolka, 1989).

The most thorough analysis of intertemporal structural change was undertaken by Carter (1970).[25] She analysed the US I–O tables for 1939, 1947, and 1958, using a linear programming approach to simulate the allocation of investment in different techniques and across sectors. With respect to the changes in intermediate input structures, Carter concluded that they are relatively more stable than primary factors and sensitive to relative prices. With respect to structural change in primary factors, she concluded that both capital and labour inputs declined relative to intermediate inputs, there is no evidence that labour productivity has improved in proportion to the change in capital intensity, and changes in primary factor supply can be distinguished from adaptive changes (i.e., the economizing of primary factors through reshuffling intermediate inputs to take advantage of different rates of improvement in other sectors).

Carter concluded that there had been significant technological change between 1947 and 1958, and that most of this had represented technological progress (lower production costs). Recent work by Blair & Wycoff (1989), employing a less sophisticated methodology, shows many of these trends continuing, though with some significant exceptions in energy and trade balances (see also Feldman *et al.*, 1987).

5.2.3. Analysis of the Impacts of New Technology. There have been numerous studies utilizing I–O to examine technological change.[26] These range from the comprehensive classifactory studies by Ayres & Shapanka (1976), to specific analyses of the pace of change (see, e.g., Almon *et al.*, 1974; Stern *et al.*, 1975), or its implications for other features of the economy such as pollution loads (Ridker & Watson, 1980).

More recently, Leontief & Duchin (1986) have explored the impact of automation (primarily computers and robots) on the level and occupational composition of the workforce. Using a dynamic I–O model and a scenario approach to encompass the range of plausible underlying assumptions about future conditions and the pace of technology adoption, the authors find the likelihood of some major manpower dislocations and potential bottlenecks. The information presented could help ensure a more smooth transition.

5.3. Development Planning and Policy

The orientation of I–O models applied to economic development has changed significantly over the years. This is exemplified by the statements of one of the leading development economists of the post-war era, Hollis Chenery, in his first compendium on the subject and in his forewords to two compendia of development models that span three decades of work in this field. In Chenery & Clark (1959), the author's tone is one of advocacy of the useful role formal optimization models can play in reflecting the primary characteristics of development programs and in promoting the formulation of efficient plans. I–O serves as the general equilibrium framework necessary to overcome the limits of partial equilibrium investment criteria and ensure consistency of sectoral plans. Linear programming solutions enable the planner to seek the highest attainment of goals within resource limitations and to establish values for these resources superior to those generated by poorly functioning markets.

In his foreword to Blitzer *et al.* (1975), Chenery notes that 'there is a widespread acceptance of planning techniques that were largely experimental ten or fifteen years ago'. He also notes that the scope of development planning has broadened beyond the maximization of economic growth to include goals of employment absorption and improving income distribution. These efforts are also well represented in the formulation of more sophisticated interindustry models of that era (see, e.g., Goreaux & Manne, 1973; Chenery *et al.*, 1974; Adelman & Robinson, 1978).

Chenery also notes in the Blitzer volume that decentralization of the planning function 'is becoming increasingly popular'. In his foreword to the compendium by Dervis *et al.* (1982), he states that 'there has been a shift away from planning techniques to models that can simulate the functioning of mixed economies in which policies are implemented largely through market mechanisms'. He thus endorses approaches such as computable general equilibrium (CGE) models. CGEs vary from type to type, but most retain at least one of two major features of I–O models: (1) fixed proportions among intermediate goods, and (2) an I–O database.

5.3.1. Advantages and Scope of I–O Formulations. The assets of I–O modeling and its extensions for application to developing countries are well documented (see, e.g., Bulmer-Thomas, 1982). The I–O framework is compatible with most national accounts frameworks, especially those following the standardized practices established by the UN (see section 6 below). Extension to the SAM framework allows for the incorporation of opening and closing stocks of financial and other institutions. The double entry-bookkeeping feature of I–O provides a valuable cross-check to national accounts systems at both the sectoral and economy-wide levels. The I–O accounts framework offers a database in cases where time series data are not available, or when structural change makes the use of historical trends inappropriate. The inclusion of intermediate goods and the interdependencies among them, and between them and primary factors and final goods, offers an operational general equilibrium framework by which to make assessments. It also serves as a consistency check for the coordination of individual sector policies. This is not to deny the limitations of the basic static I–O model for application to developing economies, but the literature in this field is filled with refinements and extensions that overcome many of these limitations.

I–O based development models have been applied to the full range of problems and issues facing developing economies. These include the allocation of investment (Goreaux and Manne, 1973), import substitution (Tyler, 1976), foreign exchange constraints (Bruno *et al.*, 1970), inflation (Bulmer-Thomas, 1977), optimal growth (Tsukui, 1972), income distribution (Paukert *et al.*, (1979), as well as education planning and human capital formation (Blitzer *et al.*, 1975).

5.3.2. Model Constructs. The attributes of three I–O based models applied to developing economies are exemplified below. They reflect the pattern of historical development of models in this field though, as suggested by Chenery, the newest generation of models reflects the shift in emphasis of the potential user.

The first example is a basic static model transformed into a linear programming format by Chenery & Clark (1959), based on their work on Southern Italy (see also

Chenery *et al.*, 1953). The LP formulation allows for 'choice on the demand side' (no longer need the mix of final demand be considered fixed) and 'choice on the supply side' (no longer is the model restricted to a single way of providing a given commodity). It also allows for the explicit incorporation of resource constraints. Thus the model can be used to explore the explicit optimization of gross domestic product, the optimal combination of domestic production and imports, and the general feasibility of alternative economic development programs. The dual of the model yields shadow prices of current inputs, capital, and foreign exchange.[27]

The early development planning models were typically static in nature and failed to incorporate many of the important features of the macro-economy (savings, money, etc.) A second generation of models made significant advances in this direction (see, e.g., the review by Manne, 1974; and the compendium by Taylor, 1979). A good example of this second generation of models is that of Bruno *et al.* (1970), which focuses on the optimal allocation of investment and foreign exchange considerations in the context of dynamic comparative advantage of sectoral export expansion for Israel. The model maximizes the combination of the present value of private consumption and the end of period capital stock, subject to basic I–O technology and various sets of constraints on basic factors and upper and lower bounds on import substitution. A major feature of the model is its ability to keep the computational requirements manageable over a 15 year time horizon. This is accomplished by converting the model to an I–O version of a 'reduced form', i.e., expressing all variables in terms of final demand rather than gross output.

Finally, we summarize an example of a CGE formulation, that of Dervis *et al.* (1982). Their CGE is a multiproduct, multifactor model that simultaneously determines price and quantity. Most CGE models operate in a Walrasian fashion of adjustment to equilibrium via excess demand equations, subject to Walras's law. Individual decision makers are modeled in terms of groups of producers, purchasers of factors of production, sellers of factors, or consumers. Various fiscal and monetary variables can be included, and, in the context of developing countries, certain disequilibria can be built in as well. As in the I–O formulation, investment behaviour renders the model dynamic. Otherwise the relationship to I–O is remote. The major link is the use of I–O data for intermediate goods. In this model the production function is separable, with substitution allowed between primary factors, but fixed proportions retained within the class of intermediate goods and between them as a whole and primary factors.

5.3.3. Additional Constructs. Not all I–O models or related tools are applied to development in an optimization (centralized or decentralized) mode. For example, applications of I–O to the problem of development of lagging regions in industrialized countries have been successfully applied in a more standard form. A prime example is that of Miernyk *et al.* (1970), who employed a dynamic regional I–O model together with an ancillary industry/occupation matrix to examine the impacts of new industry on the West Virginia economy. Other examples of this type of analysis are presented by Ledent (1978), Oosterhaven (1981), and various papers in Pleeter (1980).

A short-cut to similar types of analysis are the sectoral I–O multipliers discussed in 5.1. above. These are sometimes ranked to identify 'key sectors' for the pursuit of a regional development goal. This is also a close counterpart of the notion of 'backward linkages' and 'forward linkages' as proposed, for example, by Hirschman (1958). The former are identical to the standard output multiplier defined earlier. The notion of a forward linkage pertains to the stimulus to further production provided by increased

availability of an intermediate good or primary factor. After much experimentation, the consensus now is that these linkages are equivalent to the multipliers of the supply-side, or allocation, version of the I–O model presented in Section 4 above (see, e.g., Augustinovics, 1970 for the original formulation; and Jones, 1976; and Bulmer-Thomas, 1982, for the resolution of the debate). While backward linkages represent definite chains of material requirements for production, the forward linkage is considered rather tenuous since it does not involve the same necessity of material input needs.[28] This has caused some researchers to derive a probabilistic version of the forward linkage, based on locational advantages and the strength of aggregate demand (see, e.g., Lee, 1986).

5.4. Regional and Interregional I–O Models[29]

The seminal work on regional and interregional models was published by Isard (1951) and Leontief (1953). Leontief's interregional system has been called a *balanced* model, while Isard's is known as a *pure* interregional model. The former is constructed by disaggregating a national table into a set of component regions. A pure interregional model is constructed by developing a set of regional tables. If all regions in the national economy are included, the regional tables could be aggregated to obtain a national table. If only part of the nation is included in a study area, a set of sub-regional tables can be aggregated to obtain a regional table. Isard (1951) has pointed out that the two types of models 'should not be viewed as alternatives', rather they are complements. The Leontief balanced regional model is particularly useful for determining regional implications of national projections; the pure interregional model, for determining national implications of regional projections.

5.4.1. Construction of Regional Tables. The first actual regional table was constructed for the state of Utah by Moore & Petersen (1955) using adjusted national coefficients. The first tables based on primary data were developed for the St. Louis Metropolitan area by Hirsch (1959). At least three state tables in which coefficients were derived from primary data were built at this time (Bourque & Weeks, 1963; Emerson, 1969; Miernyk *et al.*, 1970), as were two tables for metropolitan areas (Hirsch, 1959; Isard *et al.*, 1968).

These models were careful to avoid the pitfalls in I–O modeling described by Tiebout (1957). The West Virginia model (Miernyk *et al.*, 1970) projected technical coefficients over a ten-year span, using a sample of 'best practice' establishments, and included tables of labour coefficients as well as expansion and replacement capital coefficients. A study of Boulder, CO (Miernyk *et al.*, 1967), also based on survey data, incorporated an innovation suggested by Tiebout to derive income multipliers based on marginal propensities to consume for established residents and average propensities for new immigrants. These multipliers were labeled Type III to distinguish them from earlier Type I multipliers, in which households are exogenous, and Type II, with households treated endogenously.[30]

Only a small number of sub-national input–output models based on primary data were completed. As the cost of conducting sample surveys escalated, emphasis shifted to the search for improved methods of estimating regional parameters from national data. Stone & Brown (1962) developed the biproportional method for projecting matrices, which was subsequently used by a number of analysts to adjust national coefficients to a regional basis. Stone hypothesized that technical coefficients were subject to substitution and fabrication effects. The former applies to the substitution of one input for another; the latter to an increase or decrease in the value added to inputs. The critical assumption, however, is that these effects act uniformly along rows and columns.

The biproportional method was easy to test. It could be used to project direct coefficients from a prior table to estimate those for a current table. Such tests showed the method to be a relatively poor predictor of individual coefficients and, even with some cancellation of offsetting errors, average errors remained unacceptably high (see, e.g., Lynch, 1986).[31]

In cases where the RAS method has been used to generate regional coefficients from national tables, Polenske *et al.* (1986) cite several studies that have demonstrated that the regional table bears little resemblance to a survey-based table. This should surprise no one. Stone's notions of substitution and fabrication effects are conceptually sound. The idea that these effects will operate uniformly along rows and down columns, however, cannot be supported on either theoretical or empirical grounds. Indeed, the opposite assumption that coefficient changes resulting from substitution or changes in value added will *not* be identical, or even necessarily in the same direction, is much easier to support.

Alternative approaches to the construction of state input–output tables or to the estimation of 'input–output type multipliers' in the absence of complete input–output tables have been developed. These include the supply–demand pool technique (Moore & Peterson, 1955), the location quotient technique (Schaffer & Chu, 1969) and the regional purchase coefficient approach (Stevens *et al.*, 1983). These and several other alternative approaches have been evaluated both conceptually and empirically in several studies (see, e.g., Morrison & Smith, 1974; Round, 1983; Brucker *et al.*, 1987). No universally best method for estimating non-survey tables, however, has been identified to date.

Is there a way out of the dilemma of trading off accuracy for speed and economy in the construction of regional I-O tables? One possibility has been suggested by Jensen (1980). He has proposed that the accuracy of regional tables not be judged by a specific set of coefficients, say those in one or a few sectors, but by the overall or 'holistic' accuracy or usefulness of the model. One of the major differences between regional economies and their national counterparts is the degree of specialization. In most states, a relatively small number of industries account for a large share of the export base. They are also the industries likely to have large input coefficients in an input–output table.

Jensen's answer to the primary versus secondary data issue is to use both, in a two-stage hybrid approach to table formation. Non-survey or mechanical methods are used to provide an interim regional table from national tables. Survey data is then used to replace the mechanically derived coefficients in industries where there is known to be a variation in industry structure from region to region, or where coefficients are known to be analytically significant. This approach has been termed the Generation of Regional Input–Output Tables (GRIT) method, with versions applied to both regional and interregional tables, in Australia (see, e.g. Morrison *et al.*, 1982; and West *et al.*, 1984) and several other countries.

5.4.2. Construction of Multiregional Tables. One of the acknowledged weaknesses of state and other small-area input–output tables is that they view the regional economy in isolation, thereby ignoring interdependencies across boundaries (see, e.g., Miller, 1969). This is true even if the model includes reliable data on imports and exports by sector. An ideal input–output model would be a 'bottom-up' interregional model in

which tables for the 50 states, and the District of Columbia, summed to the national table. This would require all censuses of production to collect, in addition to data presently gathered, information on the origin of purchases and the destination of sales. However feasible this might be, the likelihood that it will be done in the foreseeable future is negligible. The only alternative is to attempt to construct interregional or multiregional models by disaggregating national data.

The first efforts to construct interregional I–O tables were made by Chenery *et al.* (1953), and Moses (1955). Their contributions were more conceptual than empirical, although they demonstrated that it is possible, in principle, to estimate the impacts of changes in one region on others. A major effort, extending over several years and involving a sizeable staff, was made by Polenske (1980) to construct an operational multi-regional, input–output model (MRIO).

Polenske's MRIO system was an extended and modified version of a model originally developed by Leontief & Strout (1963). One of the interesting features of the Leontief–Strout (LS) model is that it explicitly considers space through the use of gravity constants. It thus permits identification of cross-hauling where it exists, something earlier interregional models were unable to do.[32]

Conceptually, the MRIO model is a *tour de force*. The original version was based on a combination of regional and 1963 national tables and followed the standard interindustry format. An expanded set of MRIO accounts for 120 industries and 51 regions published in 1982, based on 1977 data. Like the national tables, these are organized along commodity by industry lines (see section 6). Miller (1984; p. 26) has stated that 'there are now possibilities for investigations into changes in U.S. interstate and interregional trade patterns'. But such investigations are likely to be complicated by the different methods of data reporting in the 1963 and 1977 tables.

A major problem in I–O analysis is the length of time between the preparation and publication of tables. National tables are out of data by the time they appear in print. Carter (1970) and Rose (1984) have shown that technical coefficients change for a variety of reasons. And these changes are likely to be especially pronounced during periods of rapid technological and structural change such as those that have occurred during the past decade. Because of geographical specialization, the effects of such changes are likely to be greater at the state and regional levels than for the nation as a whole. The MRIO model is also based on the assumption of stable trade coefficients. Riefler & Tiebout (1970), Beyers (1972), and Emerson (1976) have demonstrated, however, that regional trade coefficients are quite variable over time.

The MRIO model has the virtue of being a fully consistent set of accounts, e.g., the state tables sum to the national table. If all data used were available at the regional level from the same source, then it would be a truly 'bottom-up' model, thus reducing the problems inherent in any disaggregation effort. Such a model would be a powerful analytical tool whether used alone or in conjunction with macro-economic models.

Overall, one of the greatest contributions of the regional and interregional I–O literature is the breadth of applications of this empirical tool. Many of the contributions to extended I–O models and their applications discussed in a previous section were done in a regional and interregional context. Other applications include impact studies (see, e.g., Isard *et al.*, 1969), regional development (see, e.g., Miernyk *et al.*, 1970), location decisions (see, e.g., Kim *et al.*, 1983) and regional energy management (see, e.g., Blair, 1982).

5.5. The Environment

One of the most frequent topical applications of I-O over the past 20 years has been the interaction of the economy and the environment. That is not surprising given the capability of I-O to address structural interdependence. It was natural to assume that this capability might extend beyond the economy to the intricacies of ecology—the science of the interrelationship between people and their living and non-living surroundings. The disaggregated nature of I-O also was attractive because of the realization that the propensity to generate wastes differed across sectors. The interdependence and sectoral distinctions combine as useful attributes in analysing pollution abatement, which varies in difficulty—and hence cost—across sectors, and has secondary repercussions throughout the economy.

A schematic overview of the various uses of I-O for 'economic environmental analysis is presented below. It follows the general framework set forth by Isard *et al.*, (1967). Models of waste generation involve quadrants I and II, while models of resource use involve quadrants II and III. A model of recycling would then incorporate elements of I, II and III. Pollution abatement assessment models involve a combination of quadrants I and II with a two-way feedback not found in the pollution generation applications. The ultimate application is the economic ecologic model, involving all four quadrants, with the eco-system included as a set of interdependent production activities in quadrant IV.

	Economic Processes		*Ecologic Processes*	
Economic Processes	Flows between economic sectors	(II)	Flows from the economy to the eco-system	(I)
Ecologic Processes	Flows from the eco-system to the economy	(III)	Flows within the eco-system	(IV)

5.5.1. Pollution Generation and Resource Use. The use of I-O to model pollution generation was first noted briefly by Cumberland (1966), although the construction of a multi-regional I-O model, which considered the effects of water-pollution abatement on output, was started in 1962 (see Udis, 1965; and Miernyk, 1969). This type of application received a major boost from the work of Isard *et al.* (1967) and Leontief (1970a). These models used 'pollution coefficients', or direct proportional relationships between the amount of a given waste product generated and the gross output of a given sector, in a manner similar to the I-O variant 'materials balance' model of Ayres & Kneese (1969).

It is likely that the residual stream is strongly affected by economic structure. An investigation into the historical pattern by Leontief & Ford (1972) showed that much of the change in waste flows could be attributed to change in the mix of final demand, though much less than to technological change and to economic growth, over the period 1958 to 1980. I-O projections of waste flows have beem made for the USA (see, e.g., Ridker & Watson, 1980) and for the world (Leontief *et al.*, 1977). All of these projections are sobering in terms of the projected size of future waste loads.

In terms of resource use, those natural inputs that were transacted through the market have long been incorporated into I-O models. As common property resources became more scarce, however, attention was devoted to them with the aid of I-O. The majority of applications have dealt with 'water-use' coefficients, developed in the early 1960s by Lofting & McGauhey (1962) and Miernyk *et al.* (1969). The coefficients were used to calculate multipliers showing direct, indirect and induced demands on this resource. Several interesting applications of economy-resource interdependence were offered, e.g., Carter & Ireri (1970) who showed how two-way feedback from trade between California and Arizona complicated their battle over rights to Colorado River water.

5.5.2. Pollution Abatement. Leontief (1970a) is the seminal work on the general equilibrium implications of pollution control. Within the context of an I-O model, Leontief added a pollution abatement activity general enough to represent both abatement undertaken at the level of the firm or by a separate anti-pollution 'industry'. Pollution coefficients, as defined above, were used to generate estimates of gross waste flows. The policy variable of the model is the amount of (net) pollution delivered to (i.e., tolerated by) final demand. A solution to the overall balance question yields the direct cost of abatement, the amount of pollution abated, and the indirect impact on gross output. The price-value added counterpart of the model can be used to explore inflationary consequences of the environmental policy. The analytical results of this simple model indicated many of the complications associated with environmental control policy, such as the fact that pollution abatement indirectly generates wastes, raises the prices of intermediate and final goods, and changes the overall gross output of an economy.

The initial paper spawned a host of methodological refinements. Realization that impacts might vary spatially led to a multiregional formulation by Lakshmanan & Lo (1972); acknowledgement of the capital intensity of pollution abatement led to a dynamic I-O formulation by Miernyk & Sears (1974), and Rose (1976); the diminishing returns inherent in abatement led to a non-linear adjustment in abatement-goods coefficients by Rose (1976); consumption pattern effects were examined by Yan *et al.* (1975); and income distribution impacts were incorporated by Ketkar (1983).[33]

Still, more than 15 years after Leontief's initial paper, and all of its followers, we are unable to offer a definitive answer to the basic question: Do environmental controls have a net expansionary or a net contractionary effect on the economy?[34] Recently Rose (1983) reviewed the record of assessment analysis at both national and regional levels. He found that in the case of air quality regulations national studies tended toward contractionary outcomes, while regional models implied expansionary ones, thereby revealing a major inconsistency. All studies found the overall impacts to be small in absolute terms, though it should be pointed out nearly all of them dealt with incremental regulatory changes rather than the entirety of the Clean Air Act of 1970.

The major reasons for the failure of these models to reach a consistent conclusion are their omissions and biases, which often appear to be due to a lack of data or to the formulations of a model. The macro general equilibrium impacts of pollution abatement are at least as complex as those resulting from other policies, such as tax reform or monetary adjustments. Many variables are likely to be important in abatement assessment analysis, but Rose (1983) noted that about half of them are typically excluded (e.g., productivity improvements and trade competitiveness). However, many of these important variables and relationships can be included in a larger framework by combining well established extensions linking I-O to other model forms.

The biases, on the other hand, are more difficult to overcome as they represent a combination of modeling inadequacies and lack of empirical knowledge of important relationships. For example, the price-value added version of the I-O model may be helpful in pointing out how increased (or decreased) costs of production due to pollution control multiply throughout the economy (see, e.g., Evans, 1973; Giarratani, 1974), but the accuracy of the result is entirely dependent on the extent of the mark-up. Also, the accelerator investment equation often used in dynamic I-O calls for an economic expansion. However, several economists suggest that investment in pollution abatement will have various types of offsetting effects on conventional investment. Empirical estimates of this 'displacement' effect range from 33 cents to 50 cents on the dollar (see, e.g., DRI, 1980).[35]

5.5.3. Economic-Ecological Modeling. In its ideal form, this version would involve all four quadrants of Figure 2. Quadrants I through III would have the attributes we have surveyed thus far, we will therefore confine our attention to the one unique feature—quadrant IV.

The interdependence of the eco-system is as well established as that of the economic system. Various nutrient cycles, food chains, and population patterns, have been relatively stable for eons. Moreover, many of them are linear or can be approximated by linear or piece-wise linear activities. A break in the food chain through the extinction or temporary shortage of one link may cause a serious demise or extinction in the population of all species 'above' it in the hierarchy. Adaptations in the short-run are the exception rather than the rule. Interdependence means that multiplier effects are operative in the ecological domain as well as the purely economic one.

Thus I-O, or in this case the more general format of activity analysis, can serve as a valuable organizing framework for an analysis of certain aspects of the eco-system. Problems arise over the sheer complexity of some processes and the sheer volume of data required. The most extensive study of this type (see Isard *et al.*, 1971), took a team of researchers years to complete for just a small estuary in Plymouth Bay.

5.6. Energy and Natural Resources

As in the case of environmental applications, the features of structural interdependence and disaggregation made I-O attractive for study of the economic role of energy and mineral resources. However, the main attraction in this case was the extensive and detailed data on resources contained in empirical tables. Conventional neoclassical models of production express output as a function of primary factors of production, but with natural resources usually omitted or represented by a vague capital aggregate as a proxy. Even when natural resources are included in production function analyses, the term primary refers to the raw, or unrefined, form of resource commodities and would not include processed materials such as gasoline or steel. I-O tables, on the other hand, provide complete and detailed production recipes. In acknowledging the crucial role of resources in recent years, many economists have seen the need to model production in more complete terms and have adopted the comprehensive framework of the KLEM model, where the letters in the acronym stand for capital, labour, energy, and materials, respectively. Nearly all empirical KLEM models have made use of I-O data (see, e.g., Berndt and Wood, 1975).

A similar need for an I-O formulation is justified from the demand side. Except for precious gems, there is little direct consumer demand for non-fuel minerals. Instead, there is a derived demand through the use of these resources in appliances, building materials etc. The structure of I-O models—which show interindustry relationships—is ideal for such analysis.

5.6.1. Conceptual and Methodological Considerations. Since resources, and fuels in particular, have been considered to be more scarce in recent years, there has been a push to analyse the source of our dependence on them. In one direction, this has led to finding ways to trace and account for energy flows. Standard I-O multipliers were used early on to advance the analysis from one of direct requirements, or energy intensity, to total requirements, or embodied energy.[36]

Important conceptual advances have been made with respect to input substitution and an outgrowth of I-O energy research (see, e.g., Hudson and Jorgenson, 1974). In many production processes several raw fuels, such as coal, oil, and natural gas, as well as a processed energy source, such as electricity, are ready substitutes. As relative prices of these fuels change explicitly, or implicitly through, say, embargoes or environmental regulations, there is a motivation to adjust the relative proportions of fuel inputs accordingly. In an era of rapidly changing energy prices, the fixed coefficient assumption of the basic I-O model would be a liability.

The major approach to this problem has been a two stage computation process that combined neoclassical production function analysis with I-O. Lakshmanan & Lo (1972) formulated two-tier, separable production functions for certain sectors of their model. The top tier was a standard Leontief production function, but the second tier called for a further disaggregation of energy inputs and substitution within a Cobb-Douglas sub-function. The separability assumption keeps the top tier, or aggregate production function, from requiring any further adjustment, because it means that the relative quantities of the aggregates are not affected by substitution within the energy sub-function and vice versa. The most general, and probably the best known approach in this vein, is that of Hudson & Jorgenson (1974). Their model called for substitution within the material aggregate, as well as the energy one, in the context of a translog price frontier. The overall approach thus calls for a two-stage set of computations where inputs are first variables with respect to price, and then parameters in the context of conventional I-O computations. More specific formulations of the general input substitution approach have been offered by Kolk (1983), in determining the effect of price increases on the final consumption of energy, Rose (1985) in analysing the implications of energy conservation, and Rose & Chen (1988) in identifying sources of change in energy use.

5.6.2. Empirical Aspects. Much of the empirical work on the subject has stemmed from exploitation of the I-O database on energy. Nearly all empirical I-O tables are expressed in dollar terms and this is considered deficient for two reasons. First, it obscures energy input requirements because of variations in energy prices across sectors. Second, models of this type violate certain crucial 'energy conservation conditions' (i.e., accounting balances) in certain contexts as pointed out by Miller & Blair (1985).

An alternative formulation has been offered by Bullard & Herendeen (1976) which removes both of these objections. The approach has been dubbed a 'hybrid' because it calls for the conventional dollar presentation of non-energy flows and the conversion of energy flows into BTUs. The result yields meaningful energy multipliers and impact formulations.

Various structural studies have been undertaken of national and regional economies in an I-O context. These include the work of Hannon *et al.* (1983) on energy intensities of the USA, Bullard & Herendeen (1975) on the energy costs of goods in the USA and Bourque (1981) on embodied energy trade balances for Washington State.

I–O models have been applied to many important policy issues as well. This includes Just (1974) on impacts of new energy technologies, Bezdek & Hannon (1974) on energy taxation, Miernyk *et al.* (1978) on the regional impacts of rising energy prices, and Rose *et al.* (1978) on regional energy development.

Several I–O formulations have been used to make long-term projections of mineral and energy use. These include an energy-environmental growth model by Carter (1975), an application of a refined version of EPA's original SEAS Model by Ridker & Watson (1980), and a study of the future of nonfuel minerals under conditions of technological change by Leontief *et al.*, (1983). Moreover, several large-scale energy models (e.g., Brookhaven's PIES and Argonne's SAMS), have major I–O components and are used on a day-to-day basis for policy analysis. Major large scale forecasting models, such as the DRI, Chase, and Wharton models, have been used for similar purposes.[37]

6. Empirical Considerations

From the outset, Leontief has stressed that I–O is first and foremost an empirical tool. He has been a constant critic of elaborate economic models which are devoid of empirical content. His first tables, for the years 1919 and 1929, were limited to 41 intermediate sectors, their size being constrained as much by computational limitations as by the lack of data. By one of those fortunate simultaneous developments in the history of science, input–output analysis and computers evolved together. As a result, it is possible to perform the necessary computations for large-scale models such as the latest US I–O table, which contains over 500 sectors. Tables of varying sizes have been developed for about 100 nations, for every state of the USA, for regions throughout the world, and for many individual enterprises.

6.1. Data Framework and Methods of Construction

This section briefly describes the way the 1977 US I–O tables were constructed.[38] This is the sixth and latest set of published US tables, compiled by a US Government agency and based on primary data, since the first appeared in 1952. The original table, using 1947 data, was constructed by the Bureau of Labor Statistics (BLS) in the US Department of Labor (Evans & Hoffenberg, 1952).[39] It is a landmark study in terms of documentation. Documentation of subsequent tables was also extensive and the procedures, conventions and definitions used (see, e.g., Ritz, 1980) became the standards by which many tables for regions of the USA and other nations of the world were constructed.

I–O tables in the USA are based, in the main, on detailed industry statistics collected by the Bureau of the Census. The 1977 data incorporate several improvements recommended by the Office of Federal Statistical Policy and Standards (see Donahoe, 1984). It has not always been so, but the last few sets of I–O tables have been consistent with the US National Income and Product Accounts (NIPAs). The recent changes incorporated in the revision of those accounts are reflected also in the 1977 I–O tables.

Originally, the basis of an input-output model was the transactions table which showed, simultaneously, sales across $n+f$ rows and purchases reading down $n+v$ columns. Sales within the $n \times n$ matrix represented interindustry transactions. The columns designated f measured sales to final consumers, while the rows represented by v were the 'value-added' component of this table. The column sums of $n+v$ were designated as 'Total Gross Outlays', while the row sums were measures of 'Total Gross Output'. There was no counterpart of the latter two statistics in the NIPAs because they deliberately omit all intermediate transactions, which are eschewed in estimating the national income and product accounts as double-counting.

The $n \times n$ portion of the transactions table was used to calculate two related tables. The first is a table of 'direct input coefficients', computed by dividing the elements of each column by the column total including value added. The result was a new matrix of order n typically referred to as the 'A' matrix. The A matrix was then subtracted from an identity matrix and inverted to obtain a table of 'total input coefficients' (the 'Leontief Inverse').

The 1972 US I–O tables followed a more complex format (see Gigantes, 1970) in order to take into account the realities of joint production. The original three-table model has been replaced by a five-table system, which shows the relationships among commodities and the industries producing them (US BEA, 1984).

The original transactions table has been replaced by a *use* table and a *make* table. Each column in the use table shows the value of the commodities purchased by the industry listed at the top of the table from all the industries listed down the left-hand side. In the *make* table, each row shows the value of the various commodities produced by each industry listed down the side. Diagonal entries are assumed to represent the *primary* products of each industry, while the remaining row entries represent secondary products. Now the former designation 'TGO', which applied to both total gross outlays and outputs, has been replaced by distinct industry and commodity totals.

The third table is called the *commodity by industry direct requirements* table. It is similar to the A matrix in the original static Leontief model, but incorporates the industry commodity distinctions. There are now two inverse matrices rather than the original one—*a commodity by commodity total requirements* table, and an *industry by commodity total requirements* table.[40]

6.2. Empirical I–O Tables

One reason for substituting the commodity by industry approach for the traditional interindustry model is that the United Nations has recommended that it be the global standard. This effort is largely an outgrowth of the work on national income accounting by Richard Stone (see, e.g., Stone & Utting, 1953; and Stone, 1961). It culminated in the establishment of the System of National Accounts, or SNA, (see UN, 1968), which also specifies important definitions, conventions and procedures, in addition to the rectangular table format. Many of the requirements in the SNA deal with the resolution of conceptual and empirical problems that have long troubled I–O analysts, such as proper valuation of goods and services, treatment of secondary products, inclusion of non-market transactions, and distinctions among various types of government production, etc.

The SNA and the successful early applications of I–O tables, have spurred the compilation of I–O tables worldwide. Today, 53 nations have I–O tables constructed for years since 1970 (Viet, 1985). The list includes countries on each continent, developing as well as developed nations, socialist as well as market-based economies.[41]

The SNA has also facilitated the construction of I–O models of the World Economy. The first effort in this area (see Leontief *et al.*, 1977) proved successful in terms of its scope of coverage and range of applications. The approach was to divide the world into several country groupings linked together by a common trade pool of imports and exports. Through an apportioning process, this convention enabled the modelers to determine the second-order effects of individual expansions and contractions across boundaries, without having to trace origins and destinations of trade flows from individual countries. Other multicountry and world I–O models include those by Costa (1984) and Almon (1984).

In the previous section we discussed the official US I–O tables, compiled for some time now by the US Department of Commerce Bureau of Economic Analysis. A significant amount of on-going empirical work is oriented toward the enhancement of this effort, since the BEA tables are static and five to eight years out of date when they are first published. The most notable of these efforts is the work of Clopper Almon and his associates (1974), who update the BEA table, dynamize it, and add a forecasting capability to it.

At the regional level, there are many tables in existence. The cost of replicating tables constructed by survey methods in the 1960s, would be well over a million dollars, even for a small state, today. That makes this approach prohibitive. In the meantime, regional analysts are faced with the dilemma of doing nothing at all, utilizing another type of model (sometimes not as well suited to the problem at hand than an I–O) or using a less than satisfactry I–O table. One major response to this dilemma has been the development of primarily non-survey methods, capable of making use of as much survey data as is available, along with the development of computer software to provide the capability to generate I–O tables for every state, and in some cases every county of the USA (see, e.g., Stevens *et al.*, 1983; and Alward *et al.*, 1985).[42] While economies of scale, standardization, and computerization of these approaches could release resources for the eventual improvement in accuracy via the collection of more detailed significant debate continues over the acceptability of the methods used to date (cf. Brucker *et al.*, 1987). Ironically, one of the solutions to the problem is readily within grasp. That is to partition the original census data, upon which the US table is based, into their state or regional components.

7. Conclusions

Input–Output is a multifaceted field of economics. A steady stream of contributions to this relatively new field has evolved from the work of its inventor, and his immediate associates in the 1930s and early 1940s. In the mid-1950s, the major contributions came from development economists and those interested in regional problems. By the 1960s, input–output had been applied to a wide range of issues, and was combined with other model forms. In the 1970s and 1980s, it was applied to major social and environmental problems in the USA and other nations. More recently, major work has been oriented toward broader areas of social accounting, and the forecasting of technological change by economists and engineers.

The most important contribution of I–O is its numerical representation of an economy. Tables have been constructed for nearly 100 nations and for every major region of the USA. The empirical emphasis of I–O has been stressed by its originator and by those involved in building on his original work. Leontief has always argued against the pursuit of theory for its own sake, and sought to keep input–output on firm empirical grounds. At the same time, those currently involved in new areas, such as computable general equilibrium modeling, have been inclined to point to the limitations of I–O models and to venture into new directions, yet have not been hesitant to incorporate actual input–output tables and some of their inherent assumptions into models. It is appropriate that input–output models be evaluated, to a great extent, by their usefulness. It is a testament to the I–O concept that it has been in demand by those in many diverse fields of academic research as well as by policy makers over a span of 50 years. Thus, to elaborate on Dorfman's comments stated at the outset of this paper, not only is input–output a rare *original idea*, but also one that has stood the *test of time*.

Acknowledgement

Apologies are due to scores of researchers who have contributed to the voluminous input–output literature, but whose work has not been cited due to the authors' emphases and space constraints. An effort has been made to cite the seminal work in given subareas of I–O, as well as major developments in theory, empirical work, and applications, primarily in the USA. The existence of recent reviews by Stone (1984) on the historical development of I–O with emphasis on European contributions; Richardson (1985) on regional I–O multipliers; and Carter & Petri (1989) on Leontief's work enabled us to make the treatment of these subjects rather brief. The authors wish to thank Anne Carter, Faye Duchin, Ronald Miller, Karen Polenske, Rodney Jensen, and Frank Giarratani for their helpful comments on an earlier draft. We alone are responsible for the interpretations in this paper, and for any omissions or errors.

Notes

1. Leontief notes that this is the relation used by Walras in his original formulation of general equilibrium theory, and followed his terminology—'coefficients of production'. Even in his earliest work, however, Leontief acknowledged that certain inputs, such as fuels, might be subject to significant substitution possibilities.
2. The direct proportionality assumption also implies constant-returns-to-scale. At the sector level this means that increased output can also be obtained by bringing more plants on line. In addition, empirical studies have shown that long-run average cost curves for many industries are relatively flat for all but small levels of output.
3. For the purposes here, we use technological change (TC) as a general term to cover the entire range from entirely new production techniques to changes in single inputs (including factor productivity changes), and also subsume technical substitution within its bounds.
4. A more detailed discussion of the following methods is found in Rose (1984). Also space does not allow us to cite all of the applications of the methods, but just their originator(s). Two major reasons other than TC for coefficients to change will be examined separately below. In I–O models expressed in value terms, price-index changes can affect coefficients. In regional models, coefficient changes can stem from changes in trade flows.
5. Also, *non-linear I–O* (Sandberg, 1973; Lahiri, 1976) employs general functional relationships that allow coefficients to vary with endogenous variables including output. The method holds the potential of escaping the confines of the constant-returns-to-scale assumption.
6. While the accelerator model is still the most widely used investment equation in I–O models, Almon has emphasized its restrictiveness and has offered a number of alternatives (see, e.g., Almon, 1963; and Almon *et al.*, 1974).
7. Many early solution approaches to the dynamic I–O model involve the inversion of the matrix of capital coefficients. Because the B matrix is likely to be singular in more disaggregated models, alternative solutions have been derived (see, e.g., Kendrick, 1972; and Livesey, 1976).
8. Takayama (1985) offers a proof that existence and stability requirements in I–O models are equivalent.
9. More theoretical work on this subject has been done by Petri (1970), Gossling (1975), and Johansen (1978).
10. Value-added refers to returns to non-reproducible primary factors of production. It also includes monopoly profits and other forms of 'rents' and is compatible with short- and long-run equilibrium conditions, or competitive or imperfectly competitive conditions.

11. Rose *et al.* (1988) have concluded that I-O does not come inherently equipped with a theory of income distribution, except that of 'structure', i.e., overall distribution is affected by the output mix via differential payment distributions across sectors.
12. Most of the SAMs and extended I-O models to date have been applied to national or regional economic development. The findings of these applications will be discussed in later sections.
13. One difference often referred to is more apparent than real—that SAMs are more general and need not be restricted to linearity requirements. But it should be emphasized that a SAM is basically a set of accounts and not in itself a model (see Pyatt & Round, 1985). That many SAMs have served as the basis for several flex-price models, including complete computable general equilibrium models speak more for the increased prevalence of the latter model forms than for SAMs, since I-O tables have served as the database for flex-price models as well. Perhaps the major distinct advantage of SAMs is that they focus on accounting units more closely in line with the US National Income and Product Accounts and the UN System of National Accounts than do I-O tables.
14. An analogous implication arises from Miller & Blair's (1985) proof of the 'similarity' of the production and allocation matrices.
15. We note several fine points of this statement. First, a sector of an I-O table typically represents a weighted average of several techniques, though, in a static system, the fact that the weights never change allows us to treat the combination as if it were a single technique. Second, the new 'rectangular' I-O tables to be discussed below have been formulated to provide a better accounting of joint-products.
16. Brown & Giarratani (1979) have countered several of Gerking's specific criticisms and recommendations, but not his general concern about the need to identify a best estimation approach under conditions of random error in the I-O database (see Gerking, 1979).
17. The review of CGE models is purposefully brief because of the recent review by Shoven & Whalley.
18. Another indication of this complementarity is provided by Shoven & Whalley's survey which indicates that a majority of CGE models used for tax analysis have their production components based on I-O data (see, e.g., Ballard *et al.*, 1985).
19. One of the major explanations be offered is that it is inappropriate to make a simple comparison of man-hours between the USA and other countries. It is necessary to adjust for the quality of labour due to the relatively greater amount of investment in human capital in the USA. A second explanation is the importance of intermediate goods in assessing overall factor intensities. This analysis was updated to include the role of energy resources by Hillman & Bullard (1978). I-O has received frequent use in studies of trade (see Bruno *et al.*, 1970; Melvin, 1982; and the many studies discussed in Bulmer-Thomas, 1982).
20. The obverse of this application is the frequent use of I-O for strategic military planning.
21. I-O multipliers also differ according to the scope of secondary effects included (see the brief discussions in the sections on Extended Models and Regional Applicatios, as well as the extensive discussion in Richardson, 1985).
22. Since I-O is devoid of ideological content, it is used extensively in capitalist and socialist countries alike.
23. This conclusion should, of course, be tempered by consideration of product quality changes, or the introduction of new materials and products.
24. Structural decomposition analysis is a general category that encompasses multiplier decomposition analysis (discussed above) as a static special case.
25. Other studies have considered stability versus change in I-O coefficients in general (see, e.g., Leontief, 1953; Vaccara, 1970; Barker, 1975; and Sevaldson, 1976). The only general statement that arises from these studies is that coefficients are relatively stable in the short term, but change over long periods of time; and that the degree of stability is related to the extent of aggregation of data.
26. Some of these were covered in our discussion of fixed I-O coefficients in section 3 of this paper.
27. The formulation of the extended demand choice model is straightforward. Ordinary I-O structural coefficients are transformed to the more general activity analysis convention, a constraint equation is added for each primary factor, and a slack variable added for every primary factor and final good. The supply choice model adds additional activities only.

28. Actually, the backward linkage is less solid than usually represented, since it assumes perfect stability of import ratios under periods of expansion ignores capacity limitations.
29. We reiterate that many of the advances in I-O discussed in other sections of this paper are an outgrowth of regional investigations. We confine ourselves here to a discussion of those aspects of I-O that are intrinsically regional. The reader is also referred to the bibliography of regional and interregional models by Giarratani *et al.* (1976).
30. Further work on the disaggregation of the household sector at the regional level has been done by Madden & Batey (1983), Batey (1985, van Dijk & Oosterhaven (1985), Batey, Madden & Weeks (1986) and Rose & Beaumont (1988) (see also the section on Extended Models above).
31. Attempts have been made to improve on the mechanical use of the RAS method by using primary data and information gathered from industrial experts to estimate coefficients that showed the largest amount of instability over time. Paelinck & Waelbroeck (1963) used the RAS method in conjunction with supplementary information, and found that the results were better than those from using the RAS method alone. Other tests, however, have not been as encouraging. In comparing the 1967 US table with one derived using RAS, Miernyk (1975) found the mean percentage difference between the two was 126.9%. When coefficients for nine of the 84 sectors in the actual 1967 table were inserted, and the remaining coefficients calculated using RAS, the mean percentage difference *increased* to 131.3%.
32. Polenske first tested the LS model using Japanese data (1969). Later she developed the MRIO (1970; see also, Polenske *et al.*, 1972; and Rodgers, 1973) which consists of a table of input coefficients and a companion table of trade coefficients for 44 regions of the USA. Most of the regions are individual states, but some aggregation was required since transportation data were not available for all states.
33. The I-O framework was also coupled to other model forms: Evans (1973) linked it with the Chase Econometric Model to improve forecasting ability; Kohn (1971) pioneered the synthesis with linear programming to analyze optimal environmental standards; and Hollenbeck (1979) placed the I-O model in the broader context of micro-simulation to examine the effect of wage and price changes.
34. This failing is not confined to I-O assessment models. It holds true for standard econometric models as well (see Portney, 1981).
35. Abatement models have not been limited to the USA. The reader is referred to Victor (1972), Canada; Hartog & Houweling (1976), The Netherlands; and Thoss (1976), Germany.
36. An extension of these themes is 'net energy analysis', which compares the energy produced by a process with its direct and indirect energy inputs. This construct helps to reveal cases in which an economically viable alternative also may result in a net negative energy yield. Outcomes such as this, and overall concern with energy scarcity, have led Gilliland (1975) and others to suggest the usefulness of an 'energy theory of value'. The I-O framework has been offered as an appropriate means of exploring this idea, though most economists are wary of single factor theories.
37. A major complication is likely to be accentuated in future applications of I-O to resource problems. This is the unique feature referred to as the 'cumulative output effect'. It means that, *ceteris paribus*, the unit cost of extracting a non-renewable resource increases over time as successively lower quality deposits are mined. Carter (1970) noted this phenomenon in explaining the overall increase in input coefficients in the mining sectors of the US economy. Methodologically, this principle makes input coefficients in many resource industries especially unstable, and has an important bearing on forecasts of mineral demand as illustrated by Penner (1981).
38. For more complete details see US Bureau of Economic Analysis (1984). That volume also contains a list of BEA publications relating to I-O (see pp. 78–79).
39. Actually, the first national I-O table constructed by a US Government Agency (also BLS) was benchmarked to 1939. We have not discussed it because it was not an 'official' US table. That table, complied under the guidance of Professor Leontief, is published in the second edition of his first book on I-O (see Leontief, 1951).
40. The 1977 US Input–Output Tables are available in different sizes. The version published in *The Survey of Current Business* includes 85 intermediate sectors and three value-added

components, while the other two sets include 366 and 537 industry-commodity groupings, respectively.

41. Member countries of the Council for Mutual Economic Assistance (CMEA), consisting entirely of socialist countries, have developed the System of Balances of National Economy, known as MPS, as their counterpart of the SNA.

42. Several other non-survey methods were discussed in the section on Regional and Inter-regional I-O Models. We confine our attention here to the two most widely used computerized methods. The first of these methods was developed under the direction of Benjamin Stevens and utilizes the Chenery–Moses non-survey method of 'regional purchase coefficients', which in this case, are computed by statistical analysis of transportation data. The second method, known as IMPLAN, was developed under the direction of Everard Lofting and Gregory Alward. It is based on the supply-demand pool technique, supplemented by extensive data on establishments from business data services and on regional accounts from various government sources. The two methods are compared in Stevens *et al.* (1983).

References

Adelman, I. & Robinson, S. (1977) *Income Distribution Policies in Developing Countries* (Stanford, CA, Stanford University Press).

Almon, C. Jr. (1963) 'Consistent forecasting in a dynamic multi-sectoral model', *Review of Economics and Statistics*, 45, pp. 148–62.

Almon, C. Jr. (1966) *The American Economy to 1975* (New York, Harper and Row).

Almon, C. Jr. (1984) 'The INFORUM—IIASA International Systems of Input-Output Models', in *Proceedings of the Seventh International Conference on Input-Output Techniques* (New York, UN).

Almon, C. Jr., Buckler, M.B., Horwitz, L.M. & Reimbold, T.C. (1974) *Interindustry Forecasts of the American Economy* (Lexington, MA, D.C. Heath).

Alward, G. *et al.* (1985) 'Regional non-survey input-output analysis with IMPLAN', paper presented at the Meetings of the Southern Regional Science Association, Washington, DC.

Augus(z)tinovics, M. (1970) 'Methods of International and Intertemporal Comparison of Structure', in A. P. Carter & A. Brody, eds., *Contributions to Input-Output Analysis* (Amsterdam, North-Holland).

Ayres, R.U. & Kneese, A.V. (1969) 'Production, Consumption and externalities', *American Economic Review*, 59, pp. 282–97.

Ayres, R.U. & Shapanka, A. (1976) 'Explicit technological substitution forecasts in long-range input-output models', *Technological Forecasting and Social Change*, 9, pp. 113–38.

Bacharach, M. (1970) *Bi-proportional Matrices and Input-Output Change* (Cambridge, Cambridge University Press).

Ballard, C. *et al.* (1985) *A General Equilibrium Model for Tax Policy Evaluation* (Chicago, University of Chicago Press).

Barker, T.S. (1972) 'Foreign Trade in Multisectoral Models', in A. Brody & A. P. Carter, eds., *Input-Output Techniques* (Amsterdam, North-Holland).

Barna, T. (1956) 'Introduction', in T. Barna, ed., *The Structural Interdependence of the Economy* (New York, Wiley).

Batey, P.W.J. (1985) 'Input-output models for regional demographic-economic analysis', *Environment and Planning A*, 17, pp. 73–99.

Batey, P.W.J. & Madden, M. (1981) 'Demographic-economic forecasting within an activity-commodity framework', *Environment and Planning A*, 13, pp. 1067–83.

Batey, P.W.J., Madden, M. & Weeks, M.J. (1987) 'Household income and expenditure in extended input-output models', *Journal of Regional Science*, 27, pp. 341–56.

Bell, C., Hazell, P. & Slade, R. (1982) *Project Evaluation in Regional Perspective* (Baltimore, Johns Hopkins University Press).

Berndt, E.R. & Wood, D.O. (1976) 'Technology, prices and the derived demand for energy', *Review of Economics and Statistics*, 57, pp. 259–68.

Beyers, W.B. (197?) 'On the stability of regional interindustry models', *Journal of Regional Science*, 12, pp. 363–374.

Bezdek, R. & Hannon, R. (1974) 'Energy, Manpower and the Highway Trust Fund', *Science*, 185, pp. 669–75.

Blair, P. (1979) *Multiobjective Regional Energy Planning* (Boston, MA, Martinus Nijhoff).

Blair, P. & Wyckoff, A. (1989) The Changing Structure of the US Economy', in R. Miller, K. Polenske & A. Rose, eds., *Frontiers of Input-Output Analysis* (New York, Oxford).

Blitzer, C., Clark, P. & Taylor, L. (1975) *Economy-Wide Models and Development Planning* (Oxford, Oxford University Press).

Bon, R. (1984) 'Comparative stability analysis of multiregional input-output models', *Quarterly Journal of Economics*, 99, pp. 791–815.

Bourque, P.J. (1981) 'Embodied energy trade balances among regions', *International Regional Science Review*, 6, pp. 121–136.

Bourque, P.J. & Weeks, E.E. (1979) *Detailed Input-Output Tables for Washington State*, Washington Agricultural Experiment Station, Circular 508.

Bourque, P.J. *et al.* (1969) *The Washington Economy: An Input-Output Study* (Seattle, University of Washington, Graduate School of Business Administration).

Brody, A. (1970) *Proportions, Prices and Planning* (Amsterdam, North-Holland).

Brown, D.M. & Giarratani, F. (1979) 'Input-output as a simple econometric model: a comment', *Review of Economics and Statistics*, 61, pp. 621–23.

Brucker, S., Hastings, S. & Latham, W.R. (1987) 'Input-output to go: a comparison of 'ready-made' regional input-output models', *Growth and Change*, 18, pp. 12–24.

Bruno, M., Dougherty, C. & Fraenkel, M. (1970) 'Dynamic Input-Output, Trade and Development', in A. P. Carter & A. Brody, eds., *Applications of Input-Output Analysis* (Amsterdam, North-Holland).

Bullard, C.W. & Herendeen, R. (1975) 'Energy impact of consumption decisions', *Proceedings of the IEEE*, 63, pp. 484–93.

Bullard, C.W. & Sebald, A.V. (1977) 'Effects of parametric uncertainty and technical change in input-output models', *Review of Economics and Statistics*, 59, pp. 75–81.

Bulmer-Thomas, V. (1977) 'A model of inflation for Central America', *Oxford Bulletin of Economics and Statistics*, 39, pp. 319–332.

Bulmer-Thomas, V. (1978) 'Trade, structure and linkages in Costa Rica', *Journal of Development Economics*, 5, pp. 73–86.

Bulmer-Thomas, V. (1982) *Input-Output Analysis in Developing Countries* (New York, Wiley).

Carter (Grosse), A. (1953) 'The Technological Structure of the Cotton Textile Industry' in W. Leontief *et al. Studies in the Structure of the American Economy* (New York, Oxford).

Carter, A. (1963) 'Incremental Flow Coefficients for a Dynamic Input-Output Model with Changing Technology', in T. Barna, ed., *Structural Interdependence and Economic Development* (New York, St. Martin's Press).

Carter, A. (1963) 'Incremental Flow Coefficients for a Dynamic Input-Output Model with Changing Technology', in Tibor Barna, ed., *Structural Interdependence and Economic Development* (London, Macmillan).

Carter, A. (1970) *Structural Change in the American Economy* (Cambridge, MA, Havard University Press).

Carter, A. (1974) 'Energy environment and economic growth', *Bell Journal of Economics and Management Science*, 5, pp. 578–592.

Carter, A. & Petri, P. (1989) 'Leontief's contribution to economics, *Journal of Policy Modeling*, forthcoming.

Carter, H. & Ireri, D. (1972) 'Linkage of California–Arizona Input-Output Models to Analyze Water Transfer Patterns', in A. Carter & A Brody, eds., *Applications of Input-Output Analysis* (Amsterdam, North-Holland).

Catsambas, T. (1982) 'Distributional implications of US petroleum taxation', *Journal of Policy Modeling*, 4, pp. 211–222.

Chen, C.Y. & Rose, A. (1986) 'The joint stability of input-output production and allocation coefficients', paper presented at the Eighth International Conference on Input-Output Techniques, Sapporo, Japan.

Chenery, H.B. (1953) 'Process and Production Functions from Engineering Data', in W. Leontief *et al. Studies in the Structure of the American Economy* (New York, Oxford).

Chenery, H.B. & Clark, P.G. (1959) *Interindustry Economics* (New York, Wiley).

Chenery, H.B. & Watanabe, T. (1958) 'International comparisons of the structure of production', *Econometrica*, 26, pp. 487–521.

Chenery, H.B., Clark, P.G. & Cao-Pinna, V. (1953) *The Structure and Growth of the Italian Economy* (Rome, US Mutual Security Agency).

Chenery, H.B. *et al.* (1974) *Redistribution with Growth* (Oxford, Oxford University Press).

Costa, A.M. (1984) 'United Nations Global Modeling: Experimental Projection on the Basis of Alternative Procedures', in *Proceedings of the Seventh International Conference on Input-Output Techniques* (New York, UN).

Cronin, F.J. (1984) 'Analytical assumptions and causal ordering in interindustry modeling', *Southern Economic Journal*, 50, pp. 521–529.

Cumberland, J.H. (1966) 'A regional interindustry model for the analysis of development objectives', *Papers and Proceedings of the Regional Science Association*, 21, pp. 79–99.

Davis, H.C., Lofting, E.M. & Sathaye, J.A. (1977) 'A comparison of alternative methods of updating input-output coefficients', *Technological Forecasting and Social Change*, 10, pp. 79–87.

Davis, H.C. & Salkin, E.L. (1984) 'Alternative approaches to the estimation of economic impacts resulting from supply constraints', *Annals of Regional Science*, 18, pp. 25–34.

de Boer, P.M.C. (1976) 'On the relationship between production functions and input-output analysis with fixed value shares', *Weltwirtschaftliches Archiv*, 112, pp. 754–59.

de Melo, J., ed. (1988) 'SAM-based models: a symposium', *Journal of Policy Modeling*, 10, 3.

Dervis, K., de Melo, J. & Robinson, S. (1982) *General Equilibrium Models for Development Policy* (Cambridge, Cambridge University Press).

Despotakis, K. (1985) 'Economic Impact Analysis: From Input-Output to Social Accounting Matrices', Technical Note EEA-85-TN-02, Engineering-Economics Associates, Berkeley, CA.

Diewert, W.E. (1971) 'An application of the Shephard duality theorem: a generalized Leontief production function', *Journal of Political Economy*, 79, pp. 481–507.

Donahoe, G.F. (1984) 'The National Income and Production Accounts: preliminary revised estimates', *Survey of Current Business*, 64, pp. 38–41.

Dorfman, R. (1954) 'The nature and significance of input-output analysis', *Review of Economics and Statistics*, 36, pp. 121–33.

Dorfman, R. (1973) 'Wassily Leontief's contribution to economics', *Swedish Journal of Economics*, 28, pp. 430–49.

Dorfman, R., Samuelson, P. & Solow, R. (1958) *Linear Programming and Economic Analysis* (New York, McGraw-Hill).

Duchin, F. (1984) 'Automation and Its Effect on Employment and Income', in B. Collins & L. Tanner, eds., *American Jobs and the Changing Industrial Base* (Cambridge, MA, Ballinger).

Duchin, F. & Szyld, D. (1986) 'The Dynamic I-O Model', in W. Leontief & F. Duchin, eds., *The Impacts of Automation on Employment* (New York, Oxford University Press).

Eckaus, R.S., McCarthy, F.D. & Mohie-Eldin, A. (1981) 'A social accounting matrix for Egypt, 1976', *Journal of Development Economics*, 9, pp. 183–203.

Emerson, M.J. (1969) *The Interindustry Structure of the Kansas Economy*, Kansas Department of Economic Development, Report No. 21.

Emerson, M.J. (1976) 'Interregional Trade Effects in Static and Dynamic Input-Output Models', in K. R. Polenske & J. V. Skolka, eds., *Advances in Input-Output Analysis* (Cambridge MA, Ballinger).

Evans, D.W. & Hoffenberg, M. (1952) 'The interindustry relations study for 1947', *Review of Economics and Statistics*, 34, pp. 97–142.

Evans, M. (1973) 'A forecasting model applied to pollution control costs', *American Economic Review*, 63, pp. 244–251.

Feldman, S., McClain, D. & Palmer, K. (1987) 'Sources of structural change in the United States, 1963–78', *Review of Economics and Statistics*, 69, pp. 503–510.

Fisher, F., Klein, L.R. & Shinkai, Y. (1965) 'Price and Output Aggregation in the Brookings Econometric Model', in J. S. Dusenberry *et al.*, eds., *The Brookings Quarterly Econometric Model of the United States* (Chicago, Rand McNally).

Fisher, W.D. (1958) 'Criteria for aggregation in Input-Output analysis', *Review of Economics and Statistics*, 40, pp. 250–60.

Fisher, W.H. & Chilton, C.H. (1975) 'Developing Ex Ante Input-Output Flow and Capital Coefficients', in W. F. Gossling, ed., *Capital Coefficients and Dynamic Input-Output Models* (London, Input-Output Publishing Company).

Freeman, R. (1980) 'An empirical analysis of the fixed coefficients manpower requirements models', *Journal of Human Resources*, 15, pp. 176–199.

Gale, D. (1960) *The Theory of Linear Economic Models* (New York, McGraw-Hill).

Georgescu-Roegen, N. (1950) 'Leontief's system in the light of recent results', *Review of Economics and Statistics*, 32, pp. 214–22.

Gerking, S. (1976) 'Input-Output as a simple econometric model', *Review of Economics and Statistics*, 58, pp. 274–282.

Gerking, S. (1979) 'Input-Output as a simple econometric model: a reply', *Review of Economics and Statistics*, 61, pp. 623–26.

Giarratani, F. (1974) 'The price effects of pollution control', *Environment and Planning A*, 6, pp. 307–312.

Giarratani, F. (1976) 'Application of an interindustry supply model to energy issues', *Environment and Planning A*, 8, pp. 447–454.

Giarratani, F. (1980) 'The scientific basis for explanation in regional analysis', *Papers of the Regional Science Association*, 45, pp. 185–196.

Giarratani, F., *et al.* (1976) *Regional and Interregional Input-Output Analysis: An Annotated Bibliography* (Regional Research Institute, West Virginia University).

Gigantes, T. (1970) 'The Representation of Technology in Input-Output System', in A. Carter & A. Brody, eds., *Contributions to Input-Output Analysis* (Amsterdam, North-Holland).

Gilliland, M.W. (1975) 'Energy analysis and public policy', *Science*, 26, pp. 1051–56.

Ghosh, A. (1958) 'Input-output approach to an allocative system', *Economica*, 25, pp. 58–64.

Ghosh, A.M. & Sengupta, A. (1984) 'Income Distribution and the Structure of Production in an Input-Output Framework', in *Proceedings of the Seventh International Conference on Input-Output Techniques* (New York, UN).

Golladay, F. & Haveman, R. (1976) 'Regional and distributional effects of a negative income tax', *American Economic Review*, 66, pp. 629–41.

Gossling, W.F. (1975) 'A Dynamic Model of Capital Replacement', in W. F. Gossling, ed., *Capital Coefficients and Dynamic Input-Output Models* (London, Input-Output Publishing Company).

Goreux, L.M. & Manne, A.S. (1973) *Multi-Level Planning* (Amsterdam, North-Holland).

Greenfield, C.C. (1985) 'A Social Accounting Matrix for Botswana', in G. Pyatt and J. Round, eds., *Social Accounting Matrices*.

Griffin, J.M. (1977) 'Long-run production modeling with pseudo-data: electric power generation', *Bell Journal of Economics*, 8, pp. 112–27.

Grootaert, C. (1983) *The Relation Between Final Demand and Income Distribution: With Application to Japan* (Heidelberg, Springer-Verlag).

Haig, B.D. & Wood, M.P. (1976) 'A Dynamic Model for Analyzing Price Changes', in K. Polenske & J. Skolka, eds., *Advances in Input-Output Analysis* (Cambridge, MA, Ballinger).

Haring, J. & van Deventer, A. (1978) 'Indirect and induced cost-benefit analysis', *Review of Economics and Statistics*, 60, pp. 312–317.

Hannon, B. *et al.* (1984) 'A comparison of energy intensities: 1963, 1967 and 1972', *Resources and Energy*, 5, pp. 83–102.

Hartog, H. den & Houweling, A. (1976) 'Population, Pollution Abatement, and the Economic Structure of the Netherlands', in *Advances in Input-Output Analysis*.

Haveman, R. & Krutilla, J. (1968) *Unemployment, Capacity, and the Evaluation of Public Expenditures* (Baltimore, Johns Hopkins University Press).

Hawkins, D. & Simon, H.A. (1949) 'Some conditions of macroeconomic stability', *Econometrica*, 17, pp. 245–48.

Henry, M. & Martin, T. (1984) 'Estimating income distribution effects on regional input-output multipliers', *Regional Science Perspectives*, 12, pp. 33–45.

Hewings, G.J.D. (1985) *Regional Input-Output Analysis* (Beverly Hills, Sage).

Hillman, A.L. & Bullard, C.L. (1978) 'Energy, the Heckscher-Ohlin Theorem, and US International Trade', *American Economic Review*, 68, pp. 96–106.

Hirsch, W.Z. (1959) 'Interindustry relations of a metropolitan area', *Review of Economics and Statistics*, 41, pp. 360–69.

Hirschman, A.O. (1958) *The Strategy of Economic Development* (New Haven, CT, Yale University Press).

Hollenbeck, K. (1979) 'The employment and earnings impact of the regulation of stationary source pollution', *Journal of Environmental Economics and Management*, 6, pp. 208–221.

Hudson, E.A. & Jorgensen, D. (1974) 'US energy policy and economic growth, 1975–2000', *Bell Journal of Economics and Management Science*, 5, pp. 461–514.

Isard, W. (1951) 'Interregional and regional input–output analysis: a model of a space economy', *Review of Economics and Statistics*, 33, pp. 318–28.

Isard, W. & Langford, T. (1971) *Regional Input–Output Study: Recollections, Reflections and Diverse Notes on the Philadelphia Experience* (Cambridge, MA, MIT Press).

Isard, W. *et al.* (1960) *Methods of Regional Analysis: An Introduction to Regional Science* (Cambridge, MA, MIT Press).

Isard, W. *et al.* (1967) 'Linkages of socio-economic and ecological systems', *Papers and Proceedings of the Regional Science Association*, 21, pp. 79–99.

Isard, W., Schooler, E.W. & Vietorisz, T. (1959) *Industrial Complex Analysis* (Cambridge, MA, MIT Press).

Isard, W., Langford, T.W., & Romanoff, E. (1966–68) 'Philadelphia Region Input–Output Study', Philadelphia, Regional Science Research Institute.

Isard, W., Choguill, C.L., Kissin, J., Seyfarth, R.H. & Tatlock, R. (1971) *Ecologic-Economc Analysis for Regional Planning* (New York, Free Press).

Isserman, A. (1980) 'Estimating export activity in a regional economy: a theoretical and empirical analysis of alternative methods', *International Regional Science Review*, 5, pp. 155–184.

Johansen, L. (1978) 'On the theory of dynamic input–output Models with different time profiles of capital construction and finite life-time of capital equipment', *Journal of Economic Theory*, 19, pp. 513–533.

Jensen, R. (1980) 'The concept of accuracy in regional input–output models', *International Regional Science Review*, 5, pp. 139–54.

Jensen, R.C. & McGuarr, D. (1977) 'Reconciliation techniques in input–output analysis: some comparisons and implications', *Urban Studies*, 14, pp. 327–37.

Jones, L.P. (1976) 'The measurement of Hirschmanian linkages', *Quarterly Journal of Economics*, 90, pp. 323–333.

Kendrick, D. (1972) 'On the Leontief dynamic inverse', *Quarterly Journal of Economics*, 86, pp. 693–96.

Kendrick, J. (1972) *Economic Accounts and Their Uses* (New York, McGraw-Hill).

Ketkar, K. (1983) 'Environmental protection policies and the structure of the US economy', *Applied Economics*, 16, pp. 237–56.

Klein, L. (1974) *A Textbook of Econometrics*, 2nd ed. (Englewood Cliffs, NJ, Prentice-Hall).

Labys, W. & Wood, D.O. (1985) 'Energy models', in W. Vogely, ed., *Economics of the Mineral Industries* (New York, AIME).

Lahiri, S. (1976) 'Input–output analysis with scale-dependent coefficients', *Econometrica*, 44, pp. 947–61.

Lakshmanan, T.R. and Lo, F. (1972) 'A regional economic model for the assessment of effects of air pollution abatement', *Environment and Planning A*, 4, pp. 73–99.

Lee, K. (1986) 'Input–output multipliers with backward, forward and total linkages', paper presented at the Eighth International Conference on Input–Output Techniques, Sapporo, Japan.

Ledent, J. (1978) 'Regional multiplier analysis: a demometric approach', *Environment and Planning A*, 10, pp. 537–560.

Leontief, W. (1936) 'Quantitative input–output relations in the economic system of the United States', *Review of Economic[s and] Statistics*, 18, pp. 105–25.

Leontief, W. (1937) 'Interrelation of prices, output, savings and investment: a study in empirical application of economic theory of general interdependence', *Review of Economic[s and] Statistics*, 19, pp. 109–32.

Leontief, W. (1941) *The Structure of American Economy, 1919–1929: An Empirical Application of Equilibrium Analysis* (Cambridge, MA, Harvard University Press).

Leontief, W. (1946) 'Wages, profits and prices', *Quarterly Journal of Economics*, 61, pp. 26–39.

Leontief, W. (1951) *The Structure of the American Economy, 1919–39*, 2nd ed. (New York, Oxford University Press).

Leontief, W. (1953a) *Studies in the Structure of the American Economy* 'Interregional theory', in W. Leontief *et al.*, (New York, Oxford University Press).

Leontief, W. (1953b) 'Domestic production and foreign Trade: the American capital position reexamined', *Proceedings of the American Philosophical Society*, 97, pp. 332–49.

Leontief, W. (1956) 'Factor proportions and the structure of American trade: further theoretical and empirical analysis', *Review of Economics and Statistics*, 38, pp. 486–407.

Leontief, W. (1961) 'Lags and the stability of dynamic systems', *Econometrica*, 39, pp. 659–69; 'reply' by Sargan, pp. 670–73; 'rejoinder' by Leontief, pp. 674–75.

Leontief, W. (1963) 'The structure of development', *Scientific American*, 209, pp. 148–66.

Leontief, W. (1970a) 'Environmental repercussions and the economic system', *Review of Economics and Statistics*, 52, pp. 262–72.

Leontief, W. (1970b) 'The Dynamic Inverse', in A. Carter & A. Brody, eds., *Contributions to Input–Output Analysis* (Amsterdam, North-Holland).

Leontief, W. (1985) 'Why economics needs input–output analysis', *Challenge*, 28, pp. 27–35.

Leontief, W. (1986) 'Technological Change, Prices, Wages, and Rates of Return on Capital in the US Economy', *Input–Output Economics*, 2nd ed. (New York, Oxford University Press).

Leontief, W. & Strout, A. (1963) 'Multiregional Input–Output Analysis', in T. Barna, ed., *Structural Interdependence and Economic Development* (London, Macmillan).

Leontief, W. & Ford, D. (1972) 'Air pollution and the Economic Structure: Empirical Results of Input–Output Computations', in A. Brody & A. Carter, eds., *Input–Output Techniques*.

Leontief, W. & Duchin, F. (1982) *Military Spending* (New York, Oxford University Press).

Leontief, W. & Duchin, F. (1986) *The Future Impact of Automation on Workers* (New York, Oxford University Press).

Leontief, W., Carter, A. & Petri, P. (1977) *The Future of the World Economy* (New York, Oxford University Press).

Leontief, W. *et al.* (1965) 'The economic impact—industrial and regional—of the arms cut', *Review of Economics and Statistics*, 47, pp. 217–41.

Leontief, W. *et al.* (1983) *The Future of Nonfuel Minerals in the US and World Economies* (Lexington MA, Lexington Books).

L'Esperance, W.L. (1981) *The Structure and Control of a State Economy* (London, Pion).

Levine, H.S. (1962) 'Input–output analysis and Soviet planning', *American Economic Review*, 52, pp. 127–137.

Livesey, D.A. (1976) 'A minimal realization of the Leontief dynamic input–output model', in K. Polenske & J. Skolda, eds., *Advances in Input–Output Analysis* (Cambridge, MA, Ballinger).

Lofting, E. & McGauhey, P. (1963) *Economic Evaluation of Water, Part III, An Interindustry Analysis of the California Water Economy*, Water Resources Center Contribution No. 67 (Berkeley, University of California).

Lynch, R.C. (1986) 'An Assessment of the RAS Method for Updating Input–Output Tables', in Ira Sohn, ed., *Readings in Input–Output Analysis* (New York, Oxford University Press).

Manne, A. (1974) 'Multi-sector models for development planning: a survey', *Journal of Development Economics*, 1, pp. 43–69.

Manne, A. & Markowitz, H., eds. (1963) *Studies in Process Analysis* (New York, Wiley).

Melvin, J.R. (1979) 'Short run price effects of the corporate income tax and the implications for international trade', *American Economic Review*, 69, pp. 765–786.

Miernyk, W.H. (1965) *The Elements of Input–Output Analysis* (New York, Random House).

Miernyk, W.H. (1967) 'An Interindustry Forecasting Model with Water Quantity and Water Quality Constraints', *Proceedings of the Fourth Symposium on Water Resources Research*, (Water Resources Center, Ohio State University).

Miernyk, W.H. (1968) 'Long-range forecasting with a regional input–output model', *Western Economic Journal*, 6, pp. 165–176.

Miernyk, W.H. (1973) 'Regional and interregional input–output models: a reappraisal', in M. Perlman, C. Leven & B. Chinitz, eds., *Spatial, Regional and Population Economics* (London, Gordon and Breech).

Miernyk, W.H. (1975) 'The Projection of Technical Coefficients for Medium-Term Forecasting', in W. F. Gossling, ed., *Medium-Term Dynamic Forecasting* (London, Input–Output Publishing Company).

Miernyk, W.H. (1976) 'Comments on recent developments in regional input–output analysis', *International Regional Science Review*, 1, pp. 47–55.

Miernyk, W.H. & Sears, J.T. (1974) *Air Pollution Abatement and Regional Economic Development* (Lexington, MA, D. C. Heath).

Miernyk, W.H., Giarratani, F. & Socher, C. (1978) *Regional Impacts of Rising Energy Prices* (Cambridge, MA, Ballinger).

Miernyk, W.H. *et al.* (1967) *Impact of the Space Program on a Local Economy* (Morgantown, WV, West Virginia University Press).

Miernyk, W.H. *et al.* (1970) *Simulating Regional Economic Development* (Lexington, MA, D.C. Heath).
Miller, R.E. (1969) 'Interregional feedbacks in input–output models: some experimental results', *Western Economic Journal*, 7, pp. 41–50.
Miller, R.E. (1984) 'US Input–Output Data: A 1984 Update', Working Papers in Regional Science and Transportation (Philadelphia, University of Pennsylvania).
Miller, R.E. & Blair, P.D. (1985) *Input–Output Analysis: Foundations and Extentions* (Englewood Cliffs, NJ, Prentice-Hall).
Miyazawa, K. (1976) *Input–Output Analysis and the Structure of Income Distribution* (Berlin, Springer-Verlag).
Moore, F.T. & Petersen, J.W. (1955) 'Regional analysis: an interindustry model of Utah', *Review of Economics and Statistics*, 37, pp. 363–383.
Morishima, M. (1973) *Marx's Economics: A Dual Theory of Value and Growth* (Cambridge, Cambridge University Press).
Morrison, J.B., West, G.R. & Jensen, R.C. (1982) Regional Input–Output Tables for Queensland, 1978/79, Report to D.C.I.D., Department of Economics, University of Queensland.
Morrison, W.I. & Smith, P. (1974) 'Nonsurvey input–output techniques at the small area level: an evaluation', *Journal of Regional Science*, 14, pp. 1–14.
Moses, L. (1955) 'The stability of interregional trading patterns and input–output analysis', *American Economic Review*, 45, pp. 803–32.
Moses, L. (1974) 'Outputs and prices in interindustry models', *Papers of the Regional Science Association*, 32, pp. 7–18.
Orcutt, G. *et al.* (1976) *Policy Exploration Through Microanalytic Simulations* (Washington, DC, Urban Institute).
Oosterhaven, J. (1981) *Interregional Input–Output Analysis and Dutch Regional Policy Problems* (Aldershot, Gower).
Oosterhaven, J. (1983) 'Evaluating land reclamation plans for Northern Friesland', *Papers of the Regional Science Association*, 52, pp. 25–137.
Oosterhaven, J. (1988) 'On the plausibility of the supply-driven input–output model', *Journal of Regional Science*, 28, pp. 203–17.
Oosterhaven, J. & Folmer, H. (1985) 'An interregional labour market model incorporating vacancy chains and social security', *Papers of the Regional Science Association*, 58, pp. 141–55.
Paelinck, J. & Waelbroeck, J. (1963) 'Etude empirique sur l'evolution des coefficients d'input–output', *Economie Appliquée*, 16, pp. 81–111.
Paukert, F. *et al.* (1976) 'Redistribution of Income Patterns, Consumption, and Employment', in K. Polenske & J. Skolka, eds., *Advances in I–O Analysis* (Cambridge, MA, Ballinger).
Penner, P.S. (1981) 'A dynamic input–output analysis of net energy effects in single fuel economies', *Energy Systems and Policy*, 5, pp. 89–116.
Petri, P. (1972) 'Convergence and Temporal Structure in the Leontief Dynamic Model', in A. Brody & A. Carter, eds., *Input–Output Techniques* (Amsterdam, North-Holland).
Pleeter, S., ed. (1980) *Impact Analysis: Methodology and Application* (Leiden, Martinus Nijhoff).
Pleskovic, B. (1989) 'Interindustry flows in a general equilibrium model of fiscal incidence', *Journal of Policy Modeling*, forthcoming.
Polenske, K. (1969) 'A Multiregional Input–Output Model: Concept and Results paper prepared for Seminar on Input–Output Models and Transportation Planning, US Department of Transportation.
Polenske, K.R. (1970) 'Empirical Implementation of a Multiregional Input–Output Gravity Trade Model', in A. P. Carter & A. Brody, eds., *Contributions to Input–Output Analysis* (Amsterdam, North-Holland).
Polenske, K.R. (1972) 'The Implementation of a Multiregional Input–Output Model of the United States', in A. Brody & A. P. Carter, eds., *Input–Output Techniques* (Amsterdam, North-Holland).
Polenske, K.R. (1974) *State Estimates of Technology, 1963* (Lexington, MA, D.C. Heath).
Polenske, K.R. (1980) *The United States Multiregional Input–Output Accounts and Model* (Lexington, MA, D.C. Heath).
Polenske, K.R., Crown, W.H. & Mohr, M. (1986) 'A Critical Review of the RAS Literature', Multiregional Planning Report No. 30, Cambridge, Massachusetts Institute of Technology.

Portney, P. (1981) 'The macroeconomic impacts of federal regulations', *Natural Resources Journal*, 15, pp. 459–488.
Pyatt, G. (1988) 'A SAM approach to modeling', *Journal of Policy Modeling*, 10, pp. 327–352.
Pyatt, G. & Round, J. (1979) 'Accounting and fixed price multipliers in a social accounting framework', *Economic Journal*, 89, pp. 850–873.
Pyatt, G. & Round, J., eds. (1985) *Social Accounting Matrices: A Basis for Planning* (Washington, DC, The World Bank).
Pyatt, G., Roe, A.R. *et al.* (1977) *Social Accounting for Development Planning: with Special Reference to Sri Lanka* (Cambridge, Cambridge University Press).
Richardson, H. (1972) *Input–Output and Regional Economics* (London, Weidenfeld and Nicolson).
Richardson, H. (1985) 'Input–output and economic base multipliers: looking backward and forward', *Journal of Regional Science*, 25, pp. 607–661.
Ridker, R. & Watson, W.D. (1980) *To Choose a Future* (Baltimore, Johns Hopkins University Press).
Riefler, R.F. (1973) 'Interregional Input–Output: A State of the Art Survey', in G. C. Judge & T. Takayama, eds., *Studies in Economic Planning Over Space and Time* (Amsterdam, North-Holland).
Riefler, R.F. & Tiebout, C.M. (1970) 'Interregional input–output: an empirical California–Washington model', *Journal of Regional Science*, 10, pp. 135–152.
Ritz, P. (1980) 'Definitions and Conventions of the 1972 Input–Output Study', (Washington, DC, US GPO).
Robinson, S. & Roland-Holst, D. (1988) 'Macroeconomic structure and computable general equilibrium models', *Journal of Policy Modeling*, 10, pp. 353–76.
Rodgers, J.M. (1973) *State Estimates of Interregional Commodity Trade, 1963* (Lexington, MA, Lexington Books).
Rose, A. (1976) *A Dynamic Interindustry Model for the Economic Analysis of Air Pollution Abatement: Theory and Applications* (Ithaca, New York, Cornell University, Center for Urban Development Research).
Rose, A. (1983) 'Modeling the macroeconomic impact of air pollution abatement', *Journal of Regioal Science*, 23, pp. 441–59.
Rose, A. (1984) 'Technological change and input–output analysis', *Socio-Economic Planning Sciences*, 18, pp. 305–18.
Rose, A. (1985) 'Modeling energy conservation programs', *Energy Journal*, pp. 87–103.
Rose, A. & Beaumont, P. (1988) 'Interrelational income distribution multipliers for the West Virginia economy', *Journal of Regional Science* pp. 461–75.
Rose, A. & Chen, C.Y. (1988) 'Sources of change in energy use in the US 1972–1982', Working Paper No. 8707 (revised), Regional Research Institute, West Virginia University.
Rose, A., Edmunds, S. & Lofting, E. (1978) 'The economics of geothermal energy development at the regional level', *Journal of Energy and Development*, 4, pp. 126–152.
Rose, A., Nakayama, B. & Stevens, B. (1982) 'Modern energy region development and income distribution', *Journal of Environmental Economics and Management*, 9, pp. 149–64.
Rose, A., Stevens, B. & Davis, G. (1988) *Natural Resource Policy and Income Distribution* (Baltimore, Johns Hopkins University Press).
Round, J.I. (1983) 'Nonsurvey techniques: a critical review of the theory and the evidence', *International Regional Science Review*, 8, pp. 189–212.
Round, J.I. (1989) 'Decomposition of input–output and economy-wide multipliers in a regional setting', in R. Miller, K. Polenske & A. Rose, eds., *Frontiers of Input–Output Analysis* (New York, Oxford).
Samuelson, P. (1951) 'Abstract of a model concerning substitutability in open Leontief models', in T. C. Koopmans, ed., *Activity Analysis of Production and Allocation* (New York, Wiley).
Samuelson, P. (1971) 'Understanding the Marxian notion of exploitation', *Journal of Economic Literature*, 9, pp. 399–431.
Sandberg, I. (1973) 'A non-linear input–output model of a multisectoral economy', *Econometrica*, 41, pp. 1167–1182.
Sargan, J.D. (1958) 'The instability of the Leontief dynamic model', *Econometrica*, 26, pp. 381–92.
Scarf, H. (1967) 'On the Computation of Equilibrium Prices', in W. J. Fellner, ed., *Ten Economic Studies in the Tradition of Irving Fisher* (New York, Wiley).

Scarf, H. & Shoven, J. (1984) *Applied General Equilibrium Analysis* (New York, Cambridge University Press).

Schaffer, W.A. & Chu, K. (1969) 'Non-survey techniques for constructing regional interindustry models', *Papers and Proceedings of the Regional Science Association*, 23, pp. 83–101.

Sevaldson, P. (1976) 'Price changes as causes of variation in input-outpt coefficients', in K. Polenske & J. Skolka, eds., *Advances in Input-Output Analysis* (Cambridge, MA, Ballinger).

Simpson, D. & Tsukui, J. (1965) 'The fundamental structure of production', *Review of Economics and Statistics*, 47, pp. 434–446.

Skolka, J. (1989) 'Input-output anatomy of import elasticities', *Empirical Economics*, 2, pp. 123–36.

Skolka, J. (1977) 'Input-output structural decomposition analysis for Austria', *Journal of Policy Modeling*, forthcoming.

Solow, R. (1959) 'Competitive valuation in a dynamic input-output model', *Econometrica*, 27, pp. 30–53.

Stern, M.L., Ayres, R.U. & Shapanka, A. (1975) 'A model for forecasting substitution of one technology for another', *Technological Forecasting and Social Change*, 8, pp. 57–79.

Stevens, B.H. & Trainer, G. (1980) 'Error Generation in Regional Input-Output Analysis and Its Implications for Non-Survey Models,' in S. Pleeter, ed., *Economic Impact Analysis* (Boston, Martinus Nijhoff).

Stevens, B.H., Treyz, G. & Kindahl, J. (1981) 'Conjoining an input-output model and a policy analysis model', *Environment and Planning A*, 13, pp. 1029–38.

Stevens, B.H., Treyz, G.I., Ehrlich, S. & Bower, J.R. (1983) 'A new technique for the construction of non-survey regional input-output models and comparisons with two survey-based models', *International Regional Science Review*, 8, pp. 271–286.

Stone, R. (1961a) *Input-Output and National Accounts* (Paris, OECD).

Stone, R. (1961b) 'Social Accounts at the Regional Level', in W. Isard & J. H. Cumberland, eds., *Regional Economic Planning* (Paris, OEEC).

Stone, R. (1963) *A Programme for Growth* (Cambridge, Cambridge University Press).

Stone, R. (1970) 'Demographic Input-Output: An Extension of Social Accounting', in *Contributions to Input-Output Analysis.*

Stone, R. (1977) 'Forward', in G. Pyatt, A. Roe *et al.*, eds., *Social Accounting and Development Planning.*

Stone, R. (1981) 'Input-Output Analysis and Economic Planning: A Survey', in G. Castellani & P. Mazzoline, eds., *Mathematical Programming and Its Economic Applications* (Milan, Franco Angeli).

Stone, R. (1984) 'Where Are We Now? A Short Account of the Development of Input-Output Studies and Their Present Trends', in *Proceedings of the Seventh International Conference on Input-Output Techniques* (New York, UN).

Stone, R. (1985) 'The Disaggregation of the Household Sector in the National Accounts', in G. Pyatt & J. Round, eds., *Social Accounting Matrices.*

Stone, R. & Brown, A. (1962) *A Computable Model of Economic Growth* (London, Chapman and Hall).

Stone, R. & Utting, J.E.G. (1953) 'The Relation Between Input-Output Analysis and National Accounting', in *Input-Output Relations* (Leiden, Stenfert Kroees).

Stone, R., Bates, J. & Bacharach, M. (1963) *Input-Output Relationships, 1954–1966* (Cambridge, MIT Press).

Takayama, A. (1985) *Mathematical Economics*, 2nd ed. (Cambridge, Cambridge University Press).

Taylor, L. (1979) *Macro Model for Developing Countries* (New York, McGraw-Hill).

ten Raa, T. (1986) 'Dynamic Input-Output Analysis with Distributed Activities', paper presented at the Eighth International Conference on Input-Output Techniques, Sapporo, Japan.

Thoss, R. (1976) 'A Generalized Input-Output Model for Residuals Management', in K. Polenske and J. Skolka, eds. *Advances in Input-Output Analysis.*

Tiebout, C.M. (1957) 'Regional and interregional input-output models: an appraisal', *Southern Economic Journal*, 24, pp. 140–47.

Tiebout, C.M. (1969) 'An empirical regional input-output projection model: the State of Washington', *Review of Economics and Statistics*, 51, pp. 334–40.

Tinbergen, J. (1966) 'Some refinements of the semi-input-output method', *Pakistan Development Review*, 6, pp. 243–247.

Treml, V.G. (1964) 'Economic interactions in the Soviet Union', *Annual Economic Indicators for the USSR* (Joint Economic Committee, Washington, DC, US GPO).

Treyz, G., Friedlander, A.F. & Stevens, B.H. (1980) 'The employment sector of a regional policy simulation model', *Review of Economics and Statistics*, 62, pp. 63–73.

Tsukui, J. (1972) 'Optimal Path in a Non-Linear Dynamic Input-Output System: A Generalization of the Turnpike Model', in A. Brody & A. Carter, eds., *Input-Output Techniques* (Amsterdam, North-Holland).

Tyler, W.G. (1976) *Manufactured Export Expansion and Industrialization in Brazil* (Tubingen, J. C. B. Mohr).

Udis, B. (1965) 'Regional input-output analysis and water quality management', *Journal of the Rocky Mountain Social Science Association*, 5, pp. 34–44.

United Nations Industrial Development Organization (1984) *Proceedings of the Seventh International Conference on Input-Output Techniques* (New York, UN).

US Bureau of Economic Analysis (1984) 'The 1977 Input-Output table of the United States', *Survey of Current Business.*

US Bureau of Labor Statistics (1982) *National Industry/Occupation Matrix* (Washington, DC, US Department of Labor).

Vaccara, B. (1970) 'Changes overtime in input-output coefficients for the United States, in A. Carter & A. Brody, eds., *Applications of Input-Output Analysis.*

van Dijk, J. & Oosterhaven, J. (1985) 'Regional Impacts of Migrants' Expenditures: An Input-Output/Vacancy-Chain Approach', in P. W. J. Batey & M. Madden, eds., *Integrated Analysis of Regional Systems* (London, Pion).

Victor, P. (1972) *Pollution: Economy and the Environment* (London, Allen & Unwin).

Viet, V. (1985) 'Input-output standards in the SNA framework', paper presented at International Association for Research in Income and Wealth Nineteenth General Conference, Noordwijkerhout, Netherlands.

Waelbroeck, J., ed. (1976) *The Models of Project LINK* (Amsterdam, North-Holland).

West G.R., Morrison, J.B. & Jensen, R.C. (1984) 'A method for the estimation of hybrid interregional input-output tables', *Regional Studies*, 18, pp. 413–22.

Wolff, E. & Howell, D. (1989) 'Labor quality and productivity growth in the United States', in R. Miller, K. Polenske & A. Rose, eds., *Frontiers of Input-Output Analysis* (New York, Oxford).

Yan, C. & Ames, E. (1965) 'Economic interrelatedness', *Review of Economic Studies*, 32, pp. 299–310.

Yan, C. *et al.* (1975) 'Air pollution control costs and consumption pattern effects', *Journal of Environmental Economics and Management*, 2, pp. 60–68.

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TRANSBOUNDARY INCOME AND EXPENDITURE FLOWS IN REGIONAL INPUT-OUTPUT MODELS*

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ABSTRACT. Nearly all regional input-output models have been constructed without a proper accounting of inflows and outflows of personal income and personal consumption expenditures. Typically invoked is a *no cross-payments* assumption, analogous to the *no cross-hauling* assumption for commodities. We present a new accounting framework based on the classification of flows according to the location of income generation, receipt, and spending, and argue that only flows endogenous in all three respects should be part of a closed regional I-O model. We use the framework to compute the upward bias in multipliers in a typical regional I-O model. We also present several methods for estimating transboundary flows.

1. INTRODUCTION

Most of the research attention in regional input-output (I-O) modeling has been devoted to imports and exports of commodities [see, e.g., Polenske (1980) and Stevens et al. (1983)]. Data on these flows are especially important in transforming structural coefficients (direct technical requirements) into regional input coefficients (intraregional requirements) in nonsurvey-based tables. The absence of data on gross imports and exports of commodities typically results in reliance on the no-cross-hauling assumption in most nonsurvey models, which then leads to an under-estimation of interregional trade flows and, hence, the over-estimation of regional impact multipliers [see, e.g., Richardson (1985) and Stevens, Treyz, and Lahr (1989)].

Regional inflows and outflows of income and consumption expenditures are

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REBUTTAL EXHIBIT 2

also inadequately addressed in *closing* most regional I-O tables.[1] The typical approach to dealing with the problem is implicitly to assume that gross inflows or gross outflows are equal to a net flow. This *no-cross-payments* assumption is usually invoked without justification or indication of its implications. It is analogous to no-cross-hauling of commodities, and results in a still greater upward bias in regional multipliers.

The omission of *transboundary* income and expenditure flows is especially surprising in light of the attention accorded to regional accounts in the formative years of the Regional Science discipline. Charles Leven (1958) was one of the pioneers in social accounting, and he and several other members of the profession were major contributors to the conference on regional accounts in the early 1960s (Hochwald, 1961; Hirsch, 1964). Input-output accounts were one pillar of this broader framework, and the need to incorporate both commodity and income flows was stressed. Since that time, interest in the latter has steadily waned as modelers concluded that data obstacles were too great [see, e.g., Isard and Langford (1971) and Polenske (1980)] and because they had to devote so much effort to responding to questions about intraregional input-coefficient accuracy [see e.g., Morrison and Smith (1974) and Round (1983)].

The objectives of this paper are four-fold. First, we will analyze transboundary income and expenditure flows in regional I-O models and offer a new accounting framework for them. Second, we will examine the implications of the no-cross-payments assumption and related concerns about the accuracy of impact multipliers. Third, we will compare our accounting approach with the currently popular social accounting matrix framework. Fourth, we will present some ways of improving income and expenditure flow estimates using both survey and nonsurvey data.

We suggest that our proposed regional accounting framework and the data bases derived from it will be especially useful in improving I-O modeling accuracy in evaluating many important issues in regional science, geography, and economics. These include: the analysis of regional stagnation relating to income leakages and reinvestment practices associated with absentee ownership, the evaluation of differential regional impacts of national policies, and the calculation of the regional development potential of tourism. Moreover, the framework is generalizable to important issues of international concern.

2. SOURCES OF THE TRANSBOUNDARY FLOW PROBLEM

In the closed version of the I-O model, key variables are determined endogenously through a three-part propagation process that includes commodity production, income payments, and personal consumption. In an economy closed to commodity trade and transboundary factor ownership, there are no leakages from or additions to this process from the outside.

In an open economy, characteristic of most regions (and nations), factor payments, like commodity flows, are not necessarily endogenous. In particular, only a portion of the income generated within the region is paid to the region's residents, and only a portion of that income is spent on commodities produced in the region. Complicating the picture further is the fact that a portion of the income received in the region is generated outside, and that some of the consumption purchases in the region are made by nonresidents.[2]

A classification of income flows on the basis of the location of income generation, receipt, and expenditure is presented in Table 1. These three factors, distinguished according to their status as "inside the region" (R) or "outside the region" (O) result in the eight combinations, grouped according to where income is generated (originates), which are listed in the left-hand column of the table. A crosstabulation of these three factors with the two regional account categories "Income Received in the Region" and "Expenditures Made in the Region"

[1]This is true of net flows as well as gross flows in many cases. Examples of notable exceptions include the work of Miernyk (1970), Polenske (1974, 1980), Bourque (1987), Batey and Weeks (1989), and Cochrane (1990). Each of these researchers, however, addresses only a small subset of the gross regional income flows, and none, except Polenske, presents a comprehensive accounting framework. Some additional issues relating to exogenous and endogenous flows have more recently been examined by Cole (1990). A fairly comprehensive regional accounting framework appears in Treyz (1986) as part of an elaborate economic-base model. Special emphasis is given to transboundary income and expenditure flows in Tables 4–7 and their accompanying equations.

TABLE 1: Transboundary Income Flow Categories

	Income Received in the Region		Expenditures Made in the Region	
	Endogenous	Exogenous	Endogenous	Exogenous
I. Income originating in R				
A. generated & received in R				
1. generated, received & spent in R	x	—	x	—
2. generated, received in R, spent in O	x	—	n.a.	n.a.
B. generated in R, but received in O				
1. generated in R, received in O, but spent in R	n.a.	n.a.	x	—
II. Income originating in O				
A. generated in O, but received in R				
1. generated in O, but received & spent in R	—	x	—	x
2. generated in O, received in R, but spent in O	—	x	n.a.	n.a.
B. generated & received in O				
1. generated, received & spent in O	n.a.	n.a.	n.a.	n.a.
2. generated & received in O, but spent in R	n.a.	n.a.	—	x

[2]Strictly speaking, the endogeneity problem arises from both the income and expenditure sides. We will use the terms "transboundary payments," or "transboundary income," or "transboundary flows" as short-hand for the general problem, and in contrast to transboundary commodity imports and exports. Note also, the term "transboundary flows" is a general one intended to cover the explicit tracing of inflows and outflows of income and consumer expenditures in pure interregional I-O models, as well as the more vague (as to origin and destination) leakages and injections of income and consumer expenditures in multiregional and regional models.

(corresponding to the row and column to be enclosed in the I-O table), and then further divided into "endogenous" and "exogenous," results in 32 possible cells. Of these, 16 are "not applicable" (i.e., logical contradictions), 8 are empty boxes (i.e., a combination can only be either endogenous or exogenous), and 8 are meaningful distinctions (denoted by an x) that need to be considered in a full set of regional accounts.[3]

It is immediately evident from the *logical enumeration* of permutations in the table that there is only one set of completely endogenous links—case IA1—which refers to a flow of income that is generated, received, and spent inside the region. This flow, adjusted for tax and savings leakages, is the only one that should automatically be included in a closed regional model.

It is interesting to compare this *endogeneity principle* with what is typically included in the household sector of a closed nonsurvey I-O model. A typical approach is to use the sum of personal consumption expenditures in the region as the control total (for both the household row and column) for goods both produced by and imported into the region. Income payments sufficient to make these purchases are extracted from employee compensation and capital-related income components of value added. Typically, all employee compensation is included and any remaining gap is made up by a proportional inclusion of capital income payments across sectors. Few justifications for this practice exist, and it is especially wanting in light of the income inflows and outflows depicted in Table 1 that it neglects to address. The practice is compatible with crude hypotheses that suggest that all wage income is spent and that high proportions of capital income are saved. Nonetheless, no explicit tax or savings adjustment is made. No rationale is offered for the proportionality assumption by which capital income is included. Most important, the endogeneity assumption of a closed model is definitely violated. (An example is presented in Section 4 below).

The emphasis here is on nonsurvey-based I-O tables, though the problem extends, to a significant degree, to survey-based tables. The data collection effort of the latter is usually limited to technological input requirements and to determining the region of origin of inputs. To the best of our knowledge, no survey-based regional tables have been constructed with primary data on the origin (or destination) of *all* income and expenditure flows.[4]

[3]The categories presented in Table 1 neglect some subtle transboundary-flow considerations dealing with branch plants, dual residence status, and mail-order shopping. The first is likely to be significant in most regions, but poses extraordinary conceptual and empirical difficulties, while the latter two may not yet be significant in most regions. Also, the classification in Table 1 omits considerations of interregional feedbacks in the sense that an income outflow, with one exception to be discussed below, is assumed never to return. The category of interregional feedbacks [see, e.g., Miller (1986)] is, however, beyond the scope of this paper.

[4]Some nonsurvey methods, such as variants of the location quotient technique, involve implicit adjustments for endogenous flows. Also, some survey-based tables, such as the Washington State table (Bourque, Conway, and Howard, 1977; Bourque, 1987), have avoided certain of the more serious transboundary-flow problems, such as extreme assumptions regarding savings or the omission of all capital-related income inflows (see also Section 6).

3. AN IMPROVED REGIONAL INCOME-EXPENDITURE ACCOUNT FRAMEWORK

The difference between the established practice and a proper accounting of transboundary flows is illustrated in Table 2. The account categories that are candidates for inclusion in the income or expenditure side of a closed I-O model (extracted from cases in Table 1 that were not complete logical contradictions) are listed at the left of Table 2, and their endogenous/exogenous status repeated in columns 1 and 2. Examples are listed in column 3. The final two column sets contain the accounts included in "typical" and our suggested "proper" accounting procedures. Overall, the typical practice includes several categories of income and expenditures that are clearly autonomous to the region in question. For example, consumer spending in the region arising out of income received by residents but generated elsewhere is included. In addition, all tourist expenditures, and the income from which they stem, are implicitly treated as generated in the region, except in the few I-O models specifically geared to the subject [e.g., Conway (1977)].

On the other hand, our proposed method includes only the category that is purely endogenous in all three respects—the regional income generated/received/spent category as well as the somewhat anomalous category IB2. The latter, likely to be small except in economic centers of large metropolitan areas, can often be considered endogenous because the income receipt leakage to commuters is only a temporary detour in the spending stream.

The basic difference between the two accounting approaches used to close regional I-O models can be summarized as follows:

(1) The typical practice is based on an adjustment to bring income in line with total regional personal consumption expenditures. This adjustment involves only a *net* income inflow or outflow.

(2) The preferred practice would be to include only those personal consumption expenditures that can be traced to income generated in the region. This amounts to the exclusion of both *gross* income inflows and *gross* income outflows.

Thus, the distinction parallels the two general approaches to dealing with commodities. The conventional assumption of no cross-hauling stipulates that a region does not simultaneously export and import the same commodity. For the

TABLE 2: Account Categories in Closed I-O Tables

Account Category		Example	Typical Accounting Practice		Proper Accounting Practice	
			Income	Expenditure	Income	Expenditure
IA1.	$G_RR_RS_R$	standard local spending	include	include	include	include
IA2.	$G_RR_RS_O$	tourism-out spending, commuter-out spending	include	n.a.	omit	n.a.
IB2.	$G_RR_OS_R$	Commuter-in spending by regional employees	include	include	include	include
IIA1.	$G_OR_RS_R$	income inflow spending	include	include	omit	omit
IIA2.	$G_OR_RS_O$	tourism-out spending	include	n.a.	omit	n.a.
IIB2.	$G_OR_OS_R$	tourism-in spending, commuter-in spending	implicitly include	include	n.a.	omit

subject at hand, the typical practice implicitly assumes the absence of a simultaneous inflow and outflow of income or consumption, i.e., no cross-payments. For example, in a case where estimates of regional income received exceed total consumer expenditures by an amount greater than tax and savings leakages, the difference is implicitly attributed to expenditures made outside the region. Of course, the gross outflow is likely to be even greater than this figure, but is offset up to the net amount by income inflows.

4. AN ILLUSTRATION OF THE TRANSBOUNDARY FLOW PROBLEM

West Virginia Income Accounts

The transboundary flow problem and its implications for the accuracy of I-O multipliers will be illustrated with the use of a nonsurvey-based West Virginia I-O table. Three sets of income accounts pertinent to the table are presented in Table 3. The first column is derived from unpublished data on "Income by Place of Residence" (income received) tabulated by the U.S. Bureau of Economic Analysis (1984). It includes a residence adjustment for wage income by place of work, and some proprietor's income and some transfers. Gross private income for West Virginia in 1982 is estimated at $13,473 million, and, with the addition of transfers, results in a $17,122.2 million estimate of gross income. The second column of the table presents a set of West Virginia income estimates based on BEA, Internal Revenue Service, and State of West Virginia Department of Finance data, which result in a gross personal income estimate of $17,087.5 million, 0.02 percent lower than the BEA estimate.

These series can be contrasted with typical measures of income used in regional I-O tables such as the U.S. Forest Service's IMPLAN table for West Virginia (U.S. Department of Agriculture, 1986; Engineering-Economics Associates, 1986). Entries from the IMPLAN data base for West Virginia are presented in column 3 of Table 1.[5] Two components of the West Virginia I-O Table pertain to income: "Employee Compensation" (which includes various "earned income" categories of wages/salaries, proprietor's income, and farm income) and "Property-type Income" (which includes not only interest, dividend, rent, and royalty income types considered in the BEA and Rose et al. accounts, but also retained earnings and depreciation). This "gross income originating" approach helps explain why the IMPLAN estimates of capital income are so much higher than in the other two series. Ironically, this higher estimate is offset by the lack of any transfer income data in the IMPLAN accounts. Thus, the "Gross Personal Income" estimate used in the IMPLAN West Virginia table turns out to be $16,606.8 million, only 3.0 percent lower than the BEA estimate.

Finally, we note the difference between the estimates of consumption expenditure in the latter two columns of Table 3. The original estimate by Rose, Davis, and Stevens (1986) is adjusted for savings and taxes (including Social Security payments) as estimated by Rose and Beaumont (1988). Interestingly, and only by sheer coincidence, the final $14,326.9 million figure of column 2, which emanates from an income-received base, is only 2.2 percent different from the IMPLAN personal consumption expenditure estimate, which comes from the income-generated and -spent side.

The figures from column 2 of Table 3 can be used to illustrate the endogenous linkages that are consistent with the improved transboundary flow accounting framework presented earlier in this paper. Specifically, in Table 4, we show how the accounts in the previous table can be modified and used to improve the control totals of the IMPLAN I-O table. Table 4 contains three columns, pertaining to adjustments in "income received," and "consumption expenditure." Note that the consumption entry comes from the IMPLAN column of Table 3 and represents expenditures in West Virginia by residents of the state and by those residing elsewhere.

TABLE 3: West Virginia Income Accounts, 1982 (in millions of 1982 dollars)[*]

	BEA	RDS	IMPLAN
Wages/Salaries	10,121.2	10,130.9	
Other Labor Income	(1,197.4)[a]	—	10,740.2
Proprietor's Income	742.2	679.9	
Farm Income	−31.9	−31.9	
Capital Related	2,659.5	2,659.5	5,866.6[b]
Gross Private Income	13,473.0	13,438.4	16,606.8[b]
Transfers	3,649.2	3,649.2	—
Gross Personal Income	17,122.2	17,087.5	16,606.8[c]
Consumption Expenditure	—	14,326.9[d,e]	14,022.7[f]

[*]The sources for the columns are respectively, U.S. Department of Commerce (1984), Rose, Davis, and Stevens (1986), U.S. Department of Agriculture (1986).

[a]Includes employer contribution to pensions and life insurance and workman's compensation (not considered part of endogenous consumption expenditures).

[b]Includes retained earnings and depreciation.

[c]The role of transfers is ambiguous in the IMPLAN accounts.

[d]Calculated as transfers plus 80 percent of AGI.

[e]Consumption expenditure by West Virginia residents in the State and elsewhere.

[f]Consumption expenditure in West Virginia by residents of the State and by those from other states and countries.

[5]We do not single out the IMPLAN system as the only one containing an inadequate accounting of transboundary income flows. This holds true to some extent for all input-output model systems of which we are aware, including survey-based tables. For example, in a recent review of the variability of nonsurvey regional I-O models, Brucker, Hasting and Latham (1990) summarize the calculation of closed versions of the models as being based on the following data controls:

	Consumption Column	Household Row
RIMS II	National PCE & savings rate, State tax data	Residence data
SCHAFFER	Regional personal income ratios	No change
IMPLAN	Regional personal consumption, Regional population	Gross factor income
RSRI	BLS regional consumer expenditure survey	Adjust for residence & out-of-state shopping

Several other adjustments of the Regional Science Research Institute (RSRI) model are discussed in Section 6 below.

Note that the IMPLAN system has many strong features extending beyond basic I-O capabilities (U.S. Department of Agriculture, 1988). Improvements are being made in the accounting for several of the transboundary flows discussed in this paper.

TABLE 4: Endogenous Income Generation, Receipt and Expenditure Linkage Estimates for West Virginia, 1982 (in millions of 1982 dollars)

Account Category	Income Received	Consumption Expenditure
Total	$17,087.5	$14,022.7
Less:		
Transfers	3,649.2	3,649.2
Taxes + Savings	2,760.6	b
Less:		
$G_RR_RS_O$	1,445.7	c
$G_OR_RS_O$	158.5	c
$G_OR_RS_R$	1,257.3	1,257.3
$G_OR_OS_R$	a	1,300.0
Equals:		
$G_RR_RS_R$	7,766.0	7,766.0
Plus:		
$G_RR_OS_R$	50.2	50.2
Equals:		
Control Total	$7,816.2	$7,816.2

[a]Income not received in region.
[b]Taxes and savings netted out before consumption.
[c]Expenditures not made in region.

Several of the other numbers in Table 4 are taken directly from column 2 in Table 3, but some had to be estimated separately. For example, the $1.3 billion attributed to the term $G_OR_OS_R$ (primarily expenditures by out-of-state tourists) was obtained from a separate study by Goeke (1987). The spending outflow estimate (a combination of $G_OR_RS_O$ and $G_RR_RS_O$) was taken as the difference between total income spent by West Virginia residents in-state and elsewhere and total personal consumption in the State by residents, i.e., $1,604.2 = $14,326.9 − ($14,022.7 − $1,300), all in millions. (Below we will show how to divide this total into its two components.)

Perhaps the most difficult figures to estimate are income received in a state but generated elsewhere. Data on a residence adjustment for the earnings of commuters are readily available from U.S. BEA (1984), and, in this case amount to $62.2 million. But the vast majority of the combination of $G_OR_OS_R$ and $G_OR_RS_O$ in most states pertains to transboundary flows of capital-related income. We used the data on the components of this term and some admittedly crude estimates to make the adjustments.[6] The total of $1,353.3 million is based on the assumption that 80

[6]The components (in millions of 1982 dollars) are:

interest	$2,126.1 × 0.5 =	$1,063.1
dividends	338.4 × 0.8 =	270.7
royalties	114.1 × 0.1 =	11.4
rents	80.8 × 0.1 =	8.1
	$2,659.4	$1,353.3

Note that the estimate of the inflow of interest income is based on a further decomposition of this category based on the U.S. average from the NIPA accounts. We assumed that all imputed interest is

percent of dividend income, 50 percent of interest income, and 10 percent of royalty income comes from out of state. Combined with the commuting worker estimate, this yields a transboundary income total of $1,415.5. So far, however, we have included the term $G_OR_RS_O$ in both tourism-out expenditures and transboundary-income inflows, since the term has elements of both. We assume that individuals spend externally-generated income on tourism in the same proportion that they spend their total income received on tourism, i.e., $1,604.2 million/$14,326.8 million = .112. This means that $G_OR_RS_O$ is $158.2 million. Hence, $G_RR_RS_O$ is $1,445.7 million = ($1,604.2 million − $158.2 million), and $G_OR_RS_R$ is $1,257.3 million = ($1,415.5 million − $158.2 million). We suggest that our estimate of transboundary flows of capital-related income are still on the conservative side. West Virginia's GSP in 1982 was less than 1.0 percent of U.S. GNP, yet we have assumed that ownership of debt and equity of enterprises in the State is 20 percent local and of land and mineral rights 90 percent local. Employee stock plans, local bond issues and family ownership of small corporations are factors that might cause the percentage of ownership in-state to exceed the percentage of national production (or profits) attributable to West Virginia. Yet it is hard to imagine these would exceed 20 percent. The holdings of major coal companies in the State make the royalty retention rate, which we use, quite conservative as well.

Finally, we estimate the commuter/worker/shopper category ($G_RR_OS_R$) at $50.2 million, the portion of the net residence adjustment to wage and salary income that is spent. In light of the fact that $G_RR_OS_R$ is unlikely to exceed 1.0 percent of expenditure in a somewhat isolated state like West Virginia, this rough approximation is likely to be adequate.

The sum of adjustments to income received is sizeable, amounting to $9,271.3 million. Income received by the State that was also originally generated and eventually spent in the State ($G_RR_RS_R$) equals $7,776.0 million. We add to this $50.2 million corresponding to the term $G_RR_OS_R$ for a control total of $7,816.2 million on the income side. The same balance can be attained from the consumption side, though it requires the subtraction of different elements. For example, savings and taxes were implicitly netted out prior to arriving at the consumption expenditure total, and $G_RR_RS_O$ and $G_OR_RS_O$ need not be subtracted because they are not spent in the State. (Note that the term $G_OR_RS_R$ is the one transboundary-flow category common to both sets of adjustments.) Overall, the new control total is only 55.7 percent of the control total that typically would be used in closing the model—the $14,022.7 million personal consumption expenditure total of the IMPLAN I-O table.[7]

within-region, 90 percent of deposit interest is within-region, and 20 percent of bond interest is within-region (i.e., 80 percent is a transboundary in-flow as in the case of dividends).

[7]There are two approaches to using this new control total in closing the I-O table. The new control total of $7,816.2 million could first be applied to the personal consumption column, without the individual coefficients changing (note the sum of the set of these coefficients that is enclosed is less than one because of imports of personal consumption items). The income row coefficients are what would be adjusted, in conformance to the level of the endogenous income actually spent in the region ($7,816.2 million). This is the mechanism that actually reduces the multipliers. In the second approach, one begins with the $7,816.2 million control total for the income row and adds back savings and taxes before adjusting income coefficients downward. Then, the savings and tax adjusted control total is used to

Implications for the Accuracy of Type II Multipliers

How serious is the no-cross-payments assumption to I-O estimates in the West Virginia context? If we assume for the moment that the adjustments are proportional across sectors, the answer is very straightforward. A theorem by Bradley and Gander (1969) states that there is a direct proportional relationship between Type I and Type II multipliers. The implication of that theorem for our purposes is that an equal proportional reduction in consumption expenditures and income in all sectors enclosed in an I-O table will lead to an equivalent percentage reduction in the size of the induced effects of each sector's Type II income or output multipliers.

This means that if the control total for closure is reduced by 44 percent, each of the Type II multipliers is reduced by 44 percent of the difference between Type I and Type II multipliers. For example, given that the Type I West Virginia income multiplier for the Industrial Chemicals sector is 1.84 and the Type II income multiplier calculated by the conventional approach is 2.66, the correct Type II multiplier is 2.30. Thus, the induced effects have been overestimated by 78.3 percent (i.e., 0.82 versus 0.46), and the Type II multiplier was overestimated by 15.7 percent.

We should note that there are two particular sources of error for Type II multipliers that are not related to transboundary flows per se, but are related to the more general matter of endogeneity. First, government expenditures are considered as autonomous expenditures in nearly all I-O tables. Strictly speaking this means that disposable income from federal and state/local government payrolls should also be deducted from the West Virginia endogenous income/expenditure stream, and from the stream in regional I-O models in general.[8] This adjustment is a further subtraction of $1,507.1 million, or 10.7 percent of the conventional control total. Second, income received from sale of capital (most of which is capital gains) and from rents (much of which is nonbusiness rental on both the renter and rentee sides) are to a great extent autonomous as well. These receipts arise from activities that are usually not related to the overall level of regional output, or they are earned on assets located outside the region. In West Virginia in 1982, the combined total of these household financial activities was $253.2 million, or 1.8 percent of total personal consumption expenditures.

scale-down the personal consumption expenditure coefficients. Each now represents an average propensity to consume out of adjusted gross income; the sum of consumption (including imports) plus savings and taxes equals the control total. The effect of the relatively higher row control is offset by the relatively smaller personal consumption coefficients. The two approaches are equivalent when a single household row and column are present, but the latter is superior when the household row and column are distinguished by income brackets that have differentiated savings and tax rates (Miyazawa, 1976; Rose and Beaumont, 1988).

[8]The assumption is typically invoked for federal government expenditures, but sometimes not for state/local expenditures because many of these are thought to be linked to tax revenues and public service needs, both highly correlated with regional economic activity. Since the link often takes place with a lag effect and because improved economic conditions lead to a reduction of a significant portion of regional government expenditures in the form of transfers, we have chosen to view the net result as one of autonomy. As such, our error estimate in this case should be considered an upper bound.

The adjustments just noted would make the total income adjustment equal 56.8 percent. The corresponding Industrial Chemicals Industry Type II multiplier would be 2.19, meaning that the original estimate was 21.5 percent too high. Similar results are obtained for other sectors. Also, these errors are invariant to the level of intermediate sector aggregation, in contrast to the beneficial effect disaggregation has on eliminating the cross-hauling distortion.

We believe these results generalize to all empirical I-O tables except those that address the transboundary problem by omitting all capital-related income flows in their control totals (which leads to an underestimation of multipliers). Also, we should note that, although our analysis would seem to indicate impact analyses performed with IMPLAN tables would err on the high side, the IMPLAN System, to its credit, emphasizes the use of Type III multipliers. This feature by itself would yield conservative impacts, relative to most other models, thereby offsetting the transboundary error, though not perfectly unless by accident.

5. TRANSBOUNDARY FLOWS IN A SOCIAL ACCOUNTING FRAMEWORK

The social accounting matrix (SAM) is being touted as the most comprehensive approach to data collection for an economy (Pyatt and Round, 1985; Pyatt, 1988),[9] and it is reasonable to ask whether this framework adds new insights to the transboundary income flows problem. Alternatively, the question can be posed as: Does the estimation of a SAM automatically guarantee a proper accounting of transboundary flows and an accurate calculation of conventional Type II multipliers?

A SAM can be defined as an interrelated set of accounts on production, consumption, accumulation, and trade. In their empirical form, SAMs are an integration of I-O and national (regional) income and product accounts, together with elements of the flow of funds, balance of payments, and national (regional) balance sheets (Barnard, 1969).

A schematic diagram of a SAM is presented in Figure 1. Actually, it represents a minor modification of a typical SAM, as presented in Pyatt and Roe (1977), in order to better illustrate transboundary flows, i.e., factor payments are distinguished according to recipients internal or external to the region. Neglecting the shading for the moment, I-O analysts will recognize the features of the matrix pertaining to interindustry transactions, personal consumption, investment, imports, and exports. The distinctions between factors and institutions and internal and external money flows merit further attention.

The factor/institution distinction emanates from the objective of noting

[9]Note that the prevailing SAM literature gives due credit for the concept to Richard Stone for his work in the 1950s and early 1960s. However, the authors could not find a single reference in this literature to the parallel work of Leven, dating back to the mid-1950s, or to the other regional scientists contributing to the field until the involvement in this research by Jeffery Round in the mid-1970s. Note also, that much of the SAM literature also tends to omit reference to its I-O antecedents [see, e.g., a recent volume of papers edited by de Melo (1988)].

		Production Activities	Factors of Production	Institutions Accounts: Current	Institutions Accounts: Capital	Rest of Nation	Grand Total
Production Activities		interindustry transactions	0	personal consumption expenditure	investment expenditure	exports	aggregate demand = gross outputs
Factors of Production		value-added payments	0	0	0	net factor income from outside	total factor income
Institutions Accounts	Current	0	allocation of factor incomes to households	regional capital transfers	0	net non-factor income from outside	incomes of regional institutions
	Capital	0	0	savings	regional current transfers	net capital income from outside	aggregate savings
Rest of Nation		imports of intermediate goods	0	imports of consumption Goods	imports of capital goods	-	total imports
Grand Total		total costs = gross inputs	total factor income	incomes of regional institutions	aggregate investment	total trade receipts	

FIGURE 1: Schematic of a Social Accounting Matrix.

important differences in spending behavior that are not captured by functional distributions alone.[10] Institutions are defined by Pyatt and Roe (1977) as "entities having the legal right of ownership and hence being able to accumulate and provide services." They can range from socioeconomic groups (e.g., income classes, occupational categories) to private nonprofit organizations (labor unions, philanthropic foundations). In addition, the formulation allows for explicit interaction between various institutions, a definite advantage of the SAM formulation over the basic I-O model.[11]

The money flow categories pertain to explicit recognition of savings and current and capital receipts from abroad (including gifts). Categories such as these must also be included in a formal SAM to arrive at a complete income account balance for the economy. In contrast, they could be omitted from most I-O formulations. This may not be a serious failing, however, in that they are extraneous to the endogeneity cycle on which fixed-price impact multipliers should be based.[12]

[10]The intersection of this institution row and factor column maps the functional distribution of income into the size distribution of personal income.

[11]Actually a great deal of research has been done in the last decade on I-O models that include more distinctions within the payments and consumption sectors (Batey and Rose, 1990). In many cases, these extended I-O models are as able as models based on the typical SAM in accurately measuring impacts, even though the former may not be complete accounting systems.

[12]This can save a significant amount of time or anguish in dealing with the more controversial assignment of some income types, such as undistributed profits (Leven, 1963).

To what extent can the SAM provide us with a clear distinction between endogenous and exogenous flows individually, and as connected, in the endogeneity chain requirement? To help illustrate the extent to which this can be done, exogenous account categories and subcategories are shaded in Figure 1 (note, the reallocation of factor incomes and institutional transfer accounts indicated by the cross-hatched lines are actual or artificial transfers and hence are irrelevant to our main focus). From looking at the figure, however, there does not appear to be an obvious closure rule to apply. Each transboundary-flow category (from Table 1) that has a corresponding SAM category is indicated by the number in the lower left-hand corner of the appropriate partition of Figure 1. Several account categories from Table 1 are absent from or imperfectly represented in this SAM. Income generated and received in R but spent in O (category IA2) is only partially covered by spending on imports (hence, the shading extending beyond the relevant partition). The SAM fails to account for spending by a resident while outside the region.[13] Income generated in R but received and spent in O is readily excluded but cannot really be separated from income generated in R, received in O, and spent in R (IB2), which should not be excluded. Both subcategories of income generated in O but received in R (IIA1 and IIA2) are readily excluded. The null endogeneity set of income generated, received, and spent in O (IIB1) is obviously excluded. Nonetheless, the category representing tourist expenditures (IIB2) is included, though not clearly delineated as part of the personal consumption expenditure partition.

Of course, many of these partly exogenous categories are not obviously depicted in a basic I-O schema either. The point is, however, that the SAM schema fares little better in providing a guide to the endogenous/exogenous distinctions necessary to model transboundary flows and to arrive at accurate impact multipliers. It is no substitute for a *logical enumeration* of all possible exogenous/endogenous combinations and an individual assessment of each case.[14] It would appear that such a logical enumeration formulation is thus more basic than either a SAM or I-O schema of inflows and outflows. The reason, in part, is that these two-dimensional representations (i.e., mere double-entry bookkeeping) cannot capture the multidimensional and connected nature of the endogeneity cycle. None of these criticisms undercut the superior contributions of SAMs in other contexts, most notably as the empirical base for computable general equilibrium models.

[13]Interestingly, while the purchase of imports was subtracted from the endogenous flow in our illustration for West Virginia, it does not appear explicitly in Table 1. This may suggest that another dimension should have been included in the endogeneity cycle, in this case, the origin of the production of consumer goods. We are justified in dropping it from the table because it is the obvious other major attribute of a regional I-O table. It fits naturally into an empirical calculation when personal consumption coefficients are adjusted (either directly or through RPCs) to reflect local requirements, the typical form they take in regional I-O models today.

[14]This logical enumeration approach is not typically used in SAM modeling [see, e.g., the flow-chart formulation approach in Dervis et al. (1982, Appendix A)]. Note that the SAM concept can be more finely disaggregated than shown in Figure 1 and that this might lead to the identification of more transboundary flows. But this begs the question of how the modeler decides on the appropriate accounting disaggregation.

6. THE ESTIMATION OF CROSS-PAYMENTS

The results of Section 5 indicate the great potential for inaccuracies in I-O multipliers when the no-cross-payments assumption is invoked. The analysis involved some rough estimates of cross-payments in an isolated region for the purpose of illustration. Ideally, a full set of data on interregional income and expenditure flows would be readily available for estimation purposes. In the obvious absence of this ideal, the question arises as to whether there are reasonably accurate data transformations, statistical inference techniques, or ways of adapting nonsurvey data that can yield reliable results. In this section, we present several modifications stemming primarily from nonsurvey methods developed in the process of model construction by the second author.[15] These nonsurvey regional input-output models have been constructed with explicit recognition of the problem of transboundary income flows. Overall, the models are basically conservative in that they exclude feedbacks via households when there are serious doubts about whether a particular income flow is retained and respent within the region. Furthermore, incomes paid to residents of other regions are assumed not to be spent in the region in question, except in cases where special studies have been undertaken to estimate the extent of such interregional income feedbacks.

The Income Side

In the case of direct labor income, only wages and salaries are included in the endogenous category. Other labor compensation is explicitly excluded because it consists mainly of employer payments for health and other types of insurance and other noncash benefits that do not enter into take-home pay. Most property-type income (dividends, interest, and rents, etc.) is also excluded because such payments are often widely dispersed throughout the extra-regional economy. Proprietor's incomes are included, however, with wages and salaries as part of take-home pay since proprietors tend to be disproportionately regional residents (Stevens et al., 1982) and their compensation is, at least in part, a payment for their labor services in running their businesses.

The extent to which the wage, salary, and proprietor's incomes are actually paid to regional households is determined by the regional purchase coefficient (RPC) for labor. This RPC is, for obvious reasons, not estimated by the methods used for intermediate sectors (Stevens et al., 1983; Treyz and Stevens, 1985). Rather, two additional data sources are used, alternatively or in conjunction.

The first and most important data in the U.S. are provided by the "Journey to Work" reports of the *Census of Population*. These provide information on the jobs held in each MSA county (and center city) by residents of other counties and even states. Unfortunately, these data cover only MSAs. Nevertheless, they do provide

[15]Some of the methods have been explained in part or in some detail in various limited-circulation reports issued by the Regional Science Research Institute (RSRI). They are incorporated in the methodology currently used to construct the RSRI's regional input-output models. The fact that they are an integral part of the methodology and cannot be neatly separated out is one of the major reasons we did not perform a typical "before and after" simulation using the RSRI model in Section 4, but rather used the West Virginia data, which was relatively more amenable to such a comparison.

enough data to allow fairly accurate estimation of regional and interstate commuting. The latter is especially important for small states and states with major MSAs that span state boundaries.

An additional data set in the U.S. is provided by the reports of the Regional Economic Information System (REIS) of the Bureau of Economic Analysis (BEA). These data give employment and earnings generated in each state (two-digit SIC) and each county (one-digit SIC). More important, they provide a breakdown of total personal income by major source together with adjustments for Social Security taxes, transfer payments, etc. This breakdown, together with the employment and earnings by major sectors, can be used to estimate the extent to which incomes generated in a U.S. region will actually appear as payments to households in the region.

Balance across regions for these data is provided by a *residence adjustment* for each state and county, which accounts for the differences between regional earnings generated and those received. Although the residence adjustment might appear to be exactly what is needed to estimate the labor RPC, it has the defect of being a net adjustment across all regional sources of earnings. For example, if there were a zero residence adjustment, it would not be possible to tell whether there was an absence of commuting into the county or whether the earnings effects of in- and out-commuting were exactly equal. Thus the REIS data, though extremely valuable, must be used with caution, and preferably in conjunction with the journey-to-work data, in estimating labor RPCs.

The Consumption Side

Once the disposable regional income effects are determined, the problem of estimating household expenditure patterns remains. Some of the questions involved in estimating these patterns are not strictly issues of transboundary-income flows. Nevertheless, it is worth considering the entire estimation process because of the various ways in which household consumption can affect the regional economy (Stevens et al., 1982).

Although the U.S. BEA input-output data provide gross totals of personal consumption by sector and a matrix that gives the breakdown of each general type of personal consumption expenditures into each of its component sectors (U.S. Department of Commerce, 1984), these data are of somewhat limited usefulness. In particular, they are national averages, whereas consumption patterns are known to vary greatly among regions (and among income groups, household types, etc.).

Household consumption in RSRI models is based on the most recent data from the annual Consumer Expenditures Survey (CES) of the Bureau of Labor Statistics (U.S. Department of Labor, 1989). These data provide details on household consumption patterns by census region, income, and household type. The data for major regions can be specialized to states and substate areas through the use of the CES data for selected MSAs and by making adjustments to reflect the incomes and household types of the smaller regions.

Aside from regional differentiation of consumption patterns, the most important adjustments to the household columns involve sales, excise, and property taxes, and expenditures outside the region, especially on trips and vacations. The latter problem is mitigated, in part, by the data on household expenditures on vacation trips included in the CES. Expenditures made by the region's residents while visiting other regions are effectively deducted from the income available for local expenditures so that they will not, improperly, feed back through the local region's economy. It is not clear that any regional models properly handle mail-order purchases, which are a growing proportion of total retail trade. Expenditures in a region by visitors from other regions are considered to be strictly exports.

With regard to sales and excise taxes, we should note that the household expenditures reported in the CES are gross expenditures at the retail level. They, thus, include any sales and/or excise taxes that may have been added in the chain from manufacturer to final consumer.

The federal excise-tax components are, of course, uniform across the nation. Nevertheless, there are wide variations in state excise taxes on the main targets: liquor, tobacco, and gasoline. And most states, as well as selected local communities in some states, impose sales taxes that vary widely in their percentages and in the purchases to which they are applied. These taxes are subtracted, as applicable, from each type of household expenditure (as specified in the CES) before the expenditures are allocated among the detailed I-O sectors. In this way, the expenditure registered in the household consumption column for each sector is net of applicable federal, state, and local excise and sales taxes.[16] Similarly, and by methods detailed in Stevens et al. (1982), property taxes are deducted from housing expenditures to obtain the appropriate net purchases from the regional economy.[17]

The aforementioned modifications are somewhat conservative and thus result in a model system that explicitly avoids the calculation of spurious intraregional induced effects, and, hence, inflated multipliers. Clearly there is a great deal of work yet to be done in this area, especially with regard to capital-related income.

In a few specific studies, where a Lowry (1964)-type of model has been used [e.g., Department of Public Works, Commonwealth of Massachusetts (1975)], time and funds have been sufficient to collect survey data on intercounty shopping patterns within metropolitan areas. In most such studies where the counties are the regions of interest, however, it has been necessary to estimate the distributions of shopping expenditures using gravity model methods [e.g., Stevens, Bower, and Ehrlich (1981)]. More generally, the standard regional input-output models provided by RSRI and most other modelers neglect category IB2 entirely. This is unfortunate, given the continued and growing separation of the work place, home place, and shopping place.

There are also several worthwhile estimation methods not associated with the construction of the RSRI models. Especially noteworthy is the work of Conway (1979) in estimating regional property income and transfers in the combined Washington econometric-interindustry model [see also Bourque, Conway, and Howard (1977)]. For example, Washington State per capita property income is a function of U.S. per capita property income and the change in Washington's gross state product relative to the change in gross national product. This estimation procedure is thus able to capture transboundary inflows of capital-related income.

Recent work by Jackson (1986, 1989) on spatial aspects of corporate structure should prove useful in the assignment of the origin and, to a lesser extent, the destination of transboundary dividend and interest flows. Work by Rose, Stevens, and Davis (1988) indicates how a disaggregation of personal income by type facilitates empirical estimation of income flows and how to avoid double-counting some household transfers (e.g., income from estates and sale of assets). Following this theme, Rose and Kilkenny (1991) are estimating transboundary flows of major types of capital-related income from primary data. The reader is also referred to the useful work of Madden (1985) on modeling commuters within an extended I-O framework. Finally, there are some seemingly forgotten methods suggested in the Hochwald (1961; e.g., the paper by Leven) and Hirsch (1964; e.g., the paper by Hoffenberg and Devine) volumes that merit reconsideration.

[16]Not only are these taxes hard to estimate, but they raise a general question about the types of effects on the number and expenditures of households in a region that should be expected in regional impact analysis. In particular, how much of a change in the number of households will occur following a given change in employment? Answers to these and similar questions would involve an evaluation of the general applicability of regional I-O to impact analysis that would be well beyond the scope of this paper. The interested reader may want to consider some of the extensions to input-output discussed or referred to in the recent literature [e.g., Treyz and Stevens (1985) and Rose and Miernyk (1989)].

[17]The standard assumption throughout, of course, is that government expenditures and employment generate taxes but not vice versa.

7. CONCLUSIONS

In addition to the West Virginia example above, evidence of the potential for error caused by improper handling of various transboundary income flows can be found in the studies by Stevens and Trainer (1976, 1981a), Park, Mohtadi, and Kabursi (1981), Garhart and Giarratani (1987, 1989), and Batey and Weeks (1989). They all conclude that the accuracy of regional input-output models is less dependent on the accuracy of the industrial technology than on the accuracy of the regionalization of industries and households, although these authors do differ on which of the latter is most important. In the case of less-industrial regions, where the multiplier is made up disproportionately of induced effects, accuracy in the estimation of the regional household row and column is certainly of primary importance [see e.g., Hewings and Romanos (1981)]. In addition our analysis provides insights into more general issues of model closure discussed by Cole (1990) and contributors to the SAM and computable general equilibrium (CGE) literature.

The foregoing shows that the problem of transboundary income flows is both important and far from intractable. At the very least, the problem has been defined and analyzed here and a framework presented such that its nature and importance can be much better understood. This is a first step toward dealing with transboundary flows on a regular, systematic and accurate basis in the construction of both survey- and nonsurvey-based regional input-output models.

REFERENCES

Barnard, Jerald. 1969. "A Social Accounting System for Regional Development Planning," *Journal of Regional Science*, 9, 109–115.

Batey, Peter W. J. and Melvyn J. Weeks. 1989. "An Extended Input-Output Model Incorporating Employed, Unemployed and In-Migrant Households," in Ronald Miller, Karen Polenske and Adam Rose (eds.) *Frontiers of Input-Output Analysis*. New York: Oxford University Press, pp. 119–133.

Batey, Peter W. J. and Adam Rose. 1990. "Extended Input-Output Models: Progress and Potential," *International Regional Science Review*, 13, 27–49.

Bourque, Philip. 1987. *The Washington State Input-Output Study for 1982*. Graduate School of Business Administration, University of Washington.

Bourque, Phillip, Richard S. Conway, Jr., and Charles T. Havard. 1977. *The Washington Projection and Simulation Model*. Graduate School of Business Administration, University of Washington.

Bradley, Iver E. and James P. Gander. 1969. "Input-Output Multipliers: Some Theoretical Comments," *Journal of Regional Science*, 9, 309–317.

Brucker, Sharon M., Steven E. Hastings, and William R. Latham. 1990. "The Variation of Estimated Impacts from Five Regional Input-Output Models," *International Regional Science Review*, 13, 119–139.

Cochrane, Steve. 1990. "Household Linkages in a Frontier Economy," *International Regional Science Review*, 13, 183–203.

Cole, Sam. 1990. "Trickle-Up and Growth in Industrial Economies," paper presented at the North American Regional Science Association Meetings, Boston.

Conway, Richard S., Jr. 1977. "The Hawaii Population and Economic Forecasting Model," Working Paper, State of Hawaii Department of Planning and Economic Development, Honolulu.

———. 1979. "The Simulation Properties of a Regional Interindustry Econometric Model," *Papers, Regional Science Association*, 43, 45–57.

de Melo, Jaime, ed. 1988. "SAM-Based Models," *Journal of Policy Modeling*, 10, 321–528.

Department of Public Works. 1975. "Economic Impacts of the Quincy Shipyard," in *Fore River Bridge Reconstruction Evaluation*, Volume IV. Boston: Commonwealth of Massachusetts.

Engineering-Economics Associates. 1986. "West Virginia Input-Output Table," (computer tape). Berkeley, CA.

Garhart, Robert E. and Frank Giarratani. 1987. "Nonsurvey Input-Output Estimation Techniques: Evidence on the Structure of Errors," *Journal of Regional Science*, 27, 245–253.

———. 1989. "Nonsurvey Input-Output Estimation Techniques: Accuracy of Household Endogenous Multipliers," paper presented at the 11th Pacific Regional Science Association Conference.

Goeke, Patricia. 1987. Personal communication regarding "The West Virginia Tourist Study," Bureau of Business Research, West Virginia University.

Hewings, Geoffrey and Michael Romanos. 1981. "Simulating Less Developed Regional Economies Under Conditions of Limited Information," *Geographical Analysis*, 13, 373–390.

Hirsch, Werner Z., ed. 1964. *Elements of Regional Accounts*. Baltimore: Johns Hopkins University Press.

Hochwald, Werner, ed. 1961. *Design of Regional Accounts*. Baltimore: Johns Hopkins University Press.

Isard, Walter and Thomas W. Langford. 1971. *Regional Input-Output Study*. Cambridge, Massachusetts: MIT Press.

Jackson, Randall W. 1986. "Measuring the Impact of External Economic Ownership," *Geographical Analysis*, 18, 313–323.

———. 1989. "Conjoining Interindustry Linkages and Ownership Data: An Empirical Application." *Growth and Change*, 20, 34–54.

Leven, Charles L. 1958. "A Theory of Regional Social Accounting." *Papers, Regional Science Association*, 4, 221–237.

———. 1963. "Regional and Interregional Accounts in Perspective." *Journal of Regional Science*, 9, 127–144.

Lowry, Ira S. 1964. *A Model of a Metropolis*. RM-4035-RC, Santa Monica, California: The Rand Corporation.

Madden, Moss. 1985. "Demographic-Economic Analysis in a Multi-Zonal Region." *Regional Science and Urban Economics*, 15, 517–540.

Miernyk, William H. et al. 1970. *Simulating Regional Economic Development*. Lexington, Massachusetts: Lexington Books.

Miller, Ronald E. 1986. "Upper Bounds on the Sizes of Interregional Feedbacks in Multiregional Input-Output Models," *Journal of Regional Science*, 26, 285–306.

Morrison, William and Paul Smith. 1974. "Nonsurvey Input-Output Techniques at the Small Area Level: An Evaluation," *Journal of Regional Science*, 14, 1–14.

Park, Se-Hark, Malek Mohtadi and Atif Kabursi. 1981. "Errors in Regional Nonsurvey Input-Output Models: Analytical and Simulation Results," *Journal of Regional Science*, 21, 321–339.

Polenske, Karen R. 1974. *State Estimates of Technology, 1963*. Lexington, Massachusetts: Lexington Books.

———. 1980. *The United States Multiregional Input-Output Accounts and Model*. Lexington, Massachusetts: Lexington Books.

Pyatt, Graham. 1988. "A SAM Approach to Modeling," *Journal of Policy Modeling*, 10, 327–352.

Pyatt, Graham and Alan Roe. 1977. *Social Accounting for Development Planning with Special Reference to Sri Lanka*. Cambridge, U.K. Cambridge University Press.

Pyatt, Graham and Jeffrey Round. 1985. *Social Accounting Matrices. A Basis for Planning*. Washington, D.C.: The World Bank.

Richardson, Harry. 1985. "Input-Output and Economic Base Multipliers: Looking Backward and Forward," *Journal of Regional Science*, 25, 607–661.

Rose, Adam and Paul Beaumont. 1988. "Interrelational Income Distribution Multipliers for the West Virginia Economy," *Journal of Regional Science*, 28, 461–475.

Rose, Adam, Gregg E. Davis, and Brandt K. Stevens. 1986. "Distributional Impacts," in A. Rose et al. *Socio-Economic Ramifications of Coal Liquefaction Facility Siting in West Virginia*. Final Report to U.S. Department of Energy. Department of Mineral Resource Economics, West Virginia University.

Rose, Adam and Maureen Kilkenny. 1991. "Transboundary Flows of Capital-related Income: An Empirical Assessment," Final report to the National Science Foundation. The Pennsylvania State University (forthcoming).

Rose, Adam and William Miernyk. 1989. "Input-Output Analysis: The First Fifty Years," *Economic Systems Research*, 1, 229–271.

Rose, Adam, Brandt K. Stevens, and Gregg E. Davis. 1988. *Natural Resource Policy and Income Distribution*. Baltimore: Johns Hopkins University Press.

Round, Jeffery I. 1983. "Nonsurvey Techniques: A Critical Review of the Theory and the Evidence," *International Regional Science Review*, 8, 189–212.

Stevens, Benjamin H. and Glynnis A. Trainer. 1976. "The Generation of Error in Regional Input-Output Impact Models," Working Paper No. A1-76. Peace Dale, Rhode Island: Regional Science Research Institute.

———. 1981. "Error Generation in Regional Input-Output Analysis and Its Implication for Nonsurvey Models," in Saul Pleeter (ed.), *Economic Impact Analysis: Methodology and Applications*. Boston: Martinus Nijhoff.

Stevens, Benjamin H., James R. Bower, and David J. Ehrlich. 1981. "Effects of Neighborhood Economic Development on the Economic Health of the Central Business District," *RSRI Discussion Paper Series No. 127*. Peace Dale, Rhode Island: Regional Science Research Institute.

Stevens, Benjamin H., George I. Treyz, David J. Ehrlich and James R. Bower. 1981. "State Input-Output Models for Transportation Impact Analysis," *RSRI Discussion Paper Series No. 128*, Peace Dale, Rhode Island: Regional Science Research Institute.

Stevens, Benjamin H., David J. Ehrlich, James K. Kindahl, George I. Treyz, James R. Bower, and Marguerite D. Woelfel. 1982. "Basic Regional Input-Output for Transportation Impact Analysis," Handbook One of *Regional Economic Analysis for Transportation Planning*, National Cooperative Highway Research Program, National Academy of Sciences.

Stevens, Benjamin H., George I. Treyz, David J. Ehrlich and James R. Bower. 1983. "A New Technique for the Construction of Non-Survey Regional Input-Output Models," *International Regional Science Review*, 8, 271–286.

Stevens, Benjamin H., George I. Treyz and Michael L. Lahr. 1989. "On the Comparative Accuracy of RPC Estimating Techniques," in Ronald Miller, Karen Polenske, and Adam Rose (eds.), *Frontiers of Input-Output Analysis*. New York: Oxford University Press, pp. 245–257.

Treyz, George I. 1986. "Fundamentals of Regional Macroeconomic Modeling: Part 1," *Survey of Regional Literature*. Pilot Issue, 11–34.

Treyz, George I. and Benjamin H. Stevens. 1985. "The TFS Regional Modelling Methodology," *Regional Studies*, 19, 547–562.

U.S. Department of Agriculture. 1986. "West Virginia Input-Output Table," Ft. Collins, Colorado: Forest Service, Rocky Mountain Experiment Station.

U.S. Department of Agriculture. 1988. *IMPLAN User's Guide*. Ft. Collins, Colorado: Forest Service, Systems Application Unit.

U.S. Department of Commerce. 1984. "Detailed Components of Personal Income: West Virginia," Bureau of Economic Analysis (Mimeographed).

U.S. Department of Commerce. 1984. "The Input-Output Structure of the U.S. Economy, 1977," Washington, D.C.: Bureau of Economic Analysis.

U.S. Department of Labor. 1989. "Consumer Expenditure Survey: 1980–88," Washington, D.C.: Bureau of Labor Statistics.

A Meta-Analysis of the Economic Impacts of Climate Change Policy

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Abstract: This paper provides a meta-analysis of a broad set of recent studies of the economic impacts of climate change mitigation policies. It evaluates the influences of the impacts of causal factors, key economic assumptions and macroeconomic linkages on the outcome of these studies. A quantile regression analysis is also performed on the meta sample to evaluate the robustness of those key factors throughout the full range of macro findings. Results of these analyses suggest that study results are strongly driven by data inputs, economic assumptions and modeling approaches. However, they are sometimes affected in counterintuitive ways.

Keywords: *Climate Change Policy, Macroeconomic Modeling, Meta-Analysis, Quantile Regression*

JEL Classifications: *C32, C68, C83, D57, D58, Q54*

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1. Introduction

The macroeconomic impacts of climate change mitigation policies are controversial among both scholars and the policy-making community. Results range from predictions of severe economic harm to significant overall economic gains. Given the unresolved nature of this debate, this paper seeks to shed light on it by evaluating a wide range of macroeconomic studies through a meta-analytic approach. Meta-analysis is a method for evaluating a cross-section of studies on a given topic, and evaluating the impacts of assumptions, input variables and modeling approaches on the overall findings of the studies. In essence, meta-analysis is a study of studies (Borenstein et al., 2009; Lipsey and Wilson, 2001).

The purpose of this paper is to refine techniques to evaluate the relative influence of assumptions, input variables and macroeconomic linkages on a wide range of macroeconomic studies of climate change policy. Repetto and Austin (1997), Barker et al. (2002), and Barker and Jenkins (2007) have recently performed meta-analyses to evaluate several macroeconomic studies in this area. This paper expands upon that foundation by evaluating a broader set of studies (both national and sub-national) and using a broader set of techniques (including quantile regression).

Section 2 of this paper provides a discussion of the key assumptions, causal factors and modeling approaches that influence macroeconomic findings. The following three sections include the standards of any empirical paper, detailing the data, methods and results of the meta-analysis. Section 6 develops the meta-analysis further, through the use quantile regression analysis, which is particularly helpful in explaining the effect of those economic assumptions on subsets of the meta sample. Section 7 focuses on two key studies, and elaborates on how the modeling methodologies, data and economic assumptions drive their results. Section 8 summarizes the contributions of the paper.

2. Factors Affecting Macroeconomic Impacts

The economy of a state, region, or nation is a complex mega-institution. It consists of the interactions of millions of individual consumers and businesses, primarily through the workings of markets. The macroeconomic linkages work not only through markets for goods and services, but also through factors of production (labor, capital, and land and other natural resources). Even the macroeconomy of a small state is likely to involve over a million businesses because of cross-border trade.

For many years, macroeconomics was dominated by considerations of aggregate components, such as production, consumption, investment, export/imports and government spending. Over the years, there has been a growing appreciation of two considerations: 1) major differences in production across sectors, and 2) the importance of microeconomic foundations of macro relationships. These considerations are especially critical in evaluating the broader impacts of climate policy. Most mitigation and sequestration policy options are sector-specific (e.g., automobile fuel efficiency, renewable portfolio standards, and reforestation). Also, the success of their implementation depends on behavioral factors that should be taken into account in policy design (e.g., the extent of the response to a market signal like a tax or subsidy).

Each mitigation/sequestration option would ideally be linked to appropriate variables beyond its narrow on-site application. These linkages help determine the potential effect on investment, the implications for prices, and the effects on other markets in general. The outcome of this process is best measured in terms of changes in key macroeconomic indicators, such as gross domestic product (GDP) or gross state product (GSP) and employment.

2.1 Causal Factors

Below, we explain how key factors influence the macroeconomics of climate policy options. The first set of causal factors relates to macroeconomic linkages. If a policy option requires capital investment, such as energy-saving equipment, it makes a significant difference whether the investment funds are additive to the geographic area or whether they offset ordinary investment in plant and equipment or ordinary consumption. If they are additive (e.g., if they attract investors from outside the region or from increased savings within its boundaries without somehow reducing consumption there), they will, all other things equal, have a stimulating effect on the economy. If they displace other investment, the effect is unknown. It could be positive if this investment calls forth greater productivity increases than the investment that it displaces, but it is equally likely that it will have a neutral or negative effect.

Note also that the various direct positive or negative stimuli of such investments have ripple, or multiplier, effects. That is, increased production of energy-saving equipment will require successive rounds of upstream demands for inputs into the supply chain of the production process.[1] This is also true of any downside effects. The multiplier can be more than three times the impact of the direct effects for the nation as a whole and a factor of two for an average-size state. However, other considerations are likely to mute its influence.

Cost savings or cost increases associated with a policy option also have multiplier effects that spread throughout the economy. This succession of cost pass-throughs moves in the same direction as the initial stimulus or dampening effects. Savings should result in decreases in overall production costs, and hence in prices, in sectors where the product is used directly and in turn in all downstream sectors dependent on the product indirectly. Cost increases move in the other direction. However, it is important to emphasize that costs or savings are not typically passed through entirely to the next round, with the extent depending on the degree of competition in the industry. Typically, sectors with higher competitive pressures are less likely to be able to pass any costs or savings onto their customers. Also, regulated industries may not be able to pass on cost changes or will only be able to do so with some time delay.

Various offsetting effects exist in relation to the implementation of climate policy options. For example, an option that promotes energy conservation, such as household appliance efficiency, even if it involves cost savings, will have a dampening effect through a decrease in demand for electricity. In a similar vein, some policy options increase the demand for one product and therefore have a stimulating effect, while decreasing the demand for its direct substitute. Interestingly, energy conservation has another unusual aspect, often referred to as the "rebound effect." This refers to the fact that an increase in vehicle fuel efficiency, for example, makes it cheaper to drive, and hence stimulates the demand for gasoline, thereby partly offsetting the initial GHG reductions. Studies indicate that this rebound effect is on the order of 15%-20%

(see, e.g., Greene et al., 1999; Maggioni, 2008). It can be interpreted as an increase in cost per unit of emissions reduced, and has an effect on aggregate demand for gasoline in relation to other goods and services.

Another causal effect results from assumptions regarding the manner in which tax or auction revenue is spent. This consideration relates to whether or not the revenues obtained from auctioning of emission permits or establishing a carbon tax are used to reduce an existing, distorting tax, such as a sales tax. Another expansionary use is the application of these funds for research and development in lowering the costs of climate policy options in the future.

Other potential influences on macroeconomic impacts are more idiosyncratic. These relate to certain types of policy options, such as the use of nuclear power, which typically represents a relatively expensive option. Another relates to the displacement of domestic, or within-state/region, electricity generation.

Finally, the type of model used to analyze the macro impacts has an effect on the outcome (see below). Likewise, the data utilized will have a major effect. In this analysis we distinguish between primary data from actual operating experience, data obtained through a stakeholder consensus process, data from individual engineering/policy design, and secondary (published) data (see also the following section). It is not clear at the outset whether these various origins of data have positive or negative effects on macro impacts. Our formal statistical analysis helps provide some insights, however.

2.2 Macroeconomic Modeling Approaches

Three major types of models are typically used to analyze the macroeconomic impacts of climate policy. The most basic is input-output (I-O) analysis. I-O, in its most fundamental form, is a static, linear model of all purchases and sales between sectors of an economy, based on the technological relationships of production (Rose and Miernyk, 1989).

I-O models are widely applied, in part because they are inexpensive to construct and easy to use. At the same time, they are very limited. The basic model is static and unable to perform any forecasting, or to factor in technological change without serious modification. It also represents a linear view of the world. The basic units of analysis are sectors, and thus this model does not contain any behavioral content regarding the motivations of individual decision makers.

Although the I-O approach has a very sound basis in production technology and is based on extensive primary data related to purchases and sales of individual businesses, it completely omits the real workings of markets and prices. Also, I-O model calculations typically work in a unidirectional manner-- the multiplier process will automatically move in the same direction as the initial stimulus. Any offsetting, rebound, or substitution effects must be explicitly entered into the model. Most I-O models used in the United States today are constructed from the Impact Analysis for Planning (IMPLAN) system (MIG, 2010), which provides a complete data set of county- and state-level economic indicators and computer algorithms for generating non-survey-based I-O tables from a national table. Examples include Bezdek and Wendling (2005) and Pollin et al. (2009).

Computable general equilibrium (CGE) models are based on the decisions of individual producers and consumers in response to markets and prices within the bounds of explicit constraints on the availability of labor, capital, and natural resources. These models build on the I-O model's strengths (e.g., sectoral distinctions, full accounting of all inputs) and focus on interdependence, since a major source of data on which these models are built comes from I-O tables, but overcome many of its limitations (Rose, 1996).

CGE models automatically incorporate such considerations as substitution and rebound effects, and require only minor modification to ensure that investment addition/displacement is adequately analyzed. Still, these models have some shortcomings, such as the assumption that the economy is always in equilibrium, which smoothes out the adjustment process (i.e., tends to minimize adjustment costs). Most CGE models are custom-built, with a good deal of variation in the functional forms of the production and consumption relationships and closure rules (account balances in terms of endogenous and exogenous considerations). Example applications include Hanson and Laitner (2006), Oladosu and Rose (2007), Roland-Holst and Kahrl (2009), and CRA (2009).

Macroeconomic (ME) models cover the entire economy, typically in a "top-down" manner, based on aggregate relationships, such as consumption and investment. This model type usually has the advantage of a forecasting capability, and more modern versions have multisector detail. While this approach typically includes price variables, the behavioral responses are not as detailed as in a CGE model. Also, most ME models focus on aggregates, and thus one needs to carefully link policy options to the appropriate macro variables. These models are based on a statistical estimation using time series data, and therefore are considered more accurate than I-O and CGE models (which are based on single-year "calibration" and also on various down-scaling adjustment methods when one moves below the national level to the regional or state level). Most ME models are based on published data made available by the U.S. Department of Commerce. Regional Economic Models, Inc (REMI) constructs the most popular version of these models. Applications of the REMI model include Rose and Wei (2010).

3. Data

Meta-analyses have proven to be particularly robust in illuminating the influence of analytic methods on their results. While individual analyses focus on the impact of a study and its precipitant causes, meta analytic methods can bring to light the effect of assumptions made by researchers in studies on a given subject.

Given the fact that there is significant debate among scholars and policymakers regarding the potential macroeconomic impacts of changes to a national or regional economy in combating climate change, meta-analytic methods can be useful in navigating through the discourse. This is because the method uncovers more than simply cause and effect; it shows how the base economic and behavioral assumptions made by researchers influence that relationship.

The data for the meta-analysis presented in this paper is a comprehensive set of recent climate impact studies that examine the impact of either state or national climate change mitigation measures on macroeconomic performance in the U.S. This is typically measured as either an increase or decrease in gross domestic/state product (GDP/GSP) or employment. Our analysis is broad in scope, as studies include a wide array of academic and research-related organizations.

In selecting relevant studies, a series of standards must be met in order to ensure that we evaluate equivalent or competing studies. Studies must evaluate the impact of a climate mitigation or sequestration measure or policy on a state, regional or national economy within the United States. Studies must evaluate the impact on GDP/GSP. This excludes studies that, for example, evaluate only the potential for growth within one sector of the economy, such as green jobs. This also excludes partial equilibrium analyses. These criteria caused us to reduce significantly the number of studies originally considered.

Moreover, some studies are more broad or comprehensive in scope than others, which necessitates another level of scrutiny. Some studies analyze dozens of disaggregated policy options separately (e.g. land-use policies versus demand-side management). Moreover, others analyze only one broad policy option (e.g. national cap-and-trade or regional carbon tax). Given this, we endeavor to analyze only the most consistent level of scope possible. For those studies

Table 1. Studies and Observations Included in the Meta-Analysis

Study Name	Number of Observations Considered	Satisfactory Observations
ACEEE (Virginia)	1	1
ACEEE (RGGI)	1	1
Bezdek and Wendling	2	0
Chamberlain	1	1
ERCOT	1	0
McKinsey	1	1
Hanson and Laitner	1	1
MISI (North Carolina)	1	1
MISI (South Carolina)	1	1
CRA (US)	1	1
CRA (Florida)	3	3
Oladosu and Rose	2	2
Paltsev et al.	1	1
Pollin et al.	1	1
Ponder et al.	6	6
Roland-Holst and Kahrl	2	2
Rose and Wei	6	6
Ross et al.	2	0
SAIC	2	2
BHI	6	6
Total	42	37

that analyze a large set of disaggregated policy options, we include up to five of their most cost-saving or cost-incurring policy options. If they also include an analysis of the sum of all policy options, we include that case as an additional observation. Table 1 above summarizes the observations included in this analysis from each study evaluated.

4. Method of Analysis

Meta-analysis typically makes use of quantitative regression analysis. The focus of the macroeconomic results is on changes in state or national product.

Analytic equivalence is particularly important in meta-analyses (Lipsey and Wilson 2001). This is because studies that are aggregated within the meta-analysis may have originally been focused on a specific level of analysis. For example, one study may suggest that a particular sequestration measure will have a positive impact of 10,000 jobs to the state of South Carolina, whereas another study may provide results that a particular sequestration measure may have a positive impact of 150,000 jobs on the national economy. Therefore, the dependent variable in this analysis is measured in terms of percent change, provides a measure of equivalence between state, regional and national macroeconomic impacts. This method of equivalence has been consistently applied in past meta studies of climate impact analyses (Barker et al. 2002; Barker and Jenkins 2007).

Furthermore, to ensure accurate accounting, when percent change figures were not available, we converted impact levels figures into percent changes using the GDP/GSP forecasted for that study's terminal year. If an official forecast was unavailable, we generated our own forecast using Holt's Double Exponential smoothing method. For the two observations for which this was necessary, the forecast correctly identified 97 and 99 percent of the variance, respectively.

As can be seen from Figure 1 below, there is a significant amount of variance in our dependent variable. At the extremes, a report by McKinsey and Company (2009) finds that there will be a positive impact to the US GDP of 2.8 percent, whereas the Beacon Hill Institute (2008) finds that there will be a negative impact of 5.12 percent to the South Carolina GSP, among equivalent cases. On the average, there is a negative 0.76 percent impact to GDP/GSP among equivalent cases.

The independent (regressor) variables for the analysis stem from the structure of the individual study designs. Each of these major variables is discussed in Section 2 and summarized in Table 2. The major independent variable in the analyses that does not usually stem from assumptions made by the researcher is *Positive Costs*, which is typically borrowed from outside sources, such as stakeholder groups or cost-engineering data, as discussed above. Table 3 summarizes the descriptive statistics of the data.

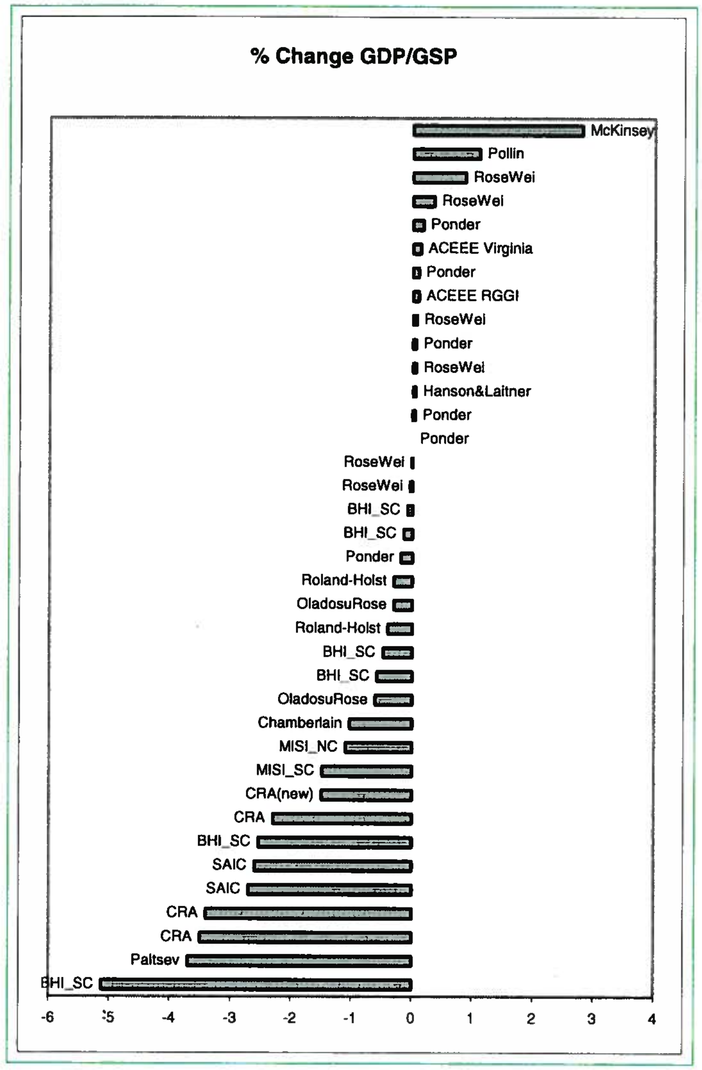

Figure 1. Range of GDP/GSP Impacts Across Studies

Table 2. Variables Analyzed in Meta-Analysis

Variables Analyzed	Definition
Positive Costs	Costs refer to the value of resources incurred in operating a mitigation or sequestration option or set of options. Zero values of this variable represent cost savings, where actions more than offset any positive expenditure. Cost estimates are taken as presented in the studies analyzed. Some are provided through the stakeholder process, or some alternative collaborative process. Others are based on cost-engineering analyses (by the author of the study or derived from secondary sources) or syntheses of the literature. Note that these are not impacts or results of the study in question.
Substitution Effects	This indicates whether the modeling effort includes the possibility for substitution across inputs, or if cost savings may be used to stimulate other spending.
Investment Addition	This refers to whether investment in mitigation or sequestration options is additive, or offsets ordinary investment in the region or nation.
Offsetting Effects	Offsetting effects are tertiary economic impacts (other than investment and substitution) that may displace the direct cost or employment impacts of the mitigation option.
Revenue Recycling	Revenue recycling refers to whether the model has accounted for the respending of particular tax or auction revenue stemming from the implementation of a policy option. Such uses include return to ratepayers as a lump-sum transfer or offsets of other taxes.
Electricity Displacement	This indicates whether the policy option causes a displacement of electricity generation with the state (or nation). This occurs for example, when local electricity generation is displaced by electricity imports from neighboring states.
Nuclear	This indicates whether the policy option contains a mechanism for the utilization of nuclear power.

Table 3. Descriptive Statistics

Variable	Mean	Min Value	Max Value
Percent Change GDP/GSP	-0.76	-5.12	2.8
Positive Costs	0.59	0	1
Substitution Effects	0.67	0	1
Nuclear	0.35	0	1
Investment Addition	0.46	0	1
Offsetting Effects	0.92	0	1
Revenue Recycling	0.16	0	1
Electricity Displacement	0.72	0	1

5. Results
5.1 Reduced Form Statistical Model

We apply meta-analysis, which uses the individual study data inputs, assumptions, background characteristics, and outcomes themselves as observations in a multivariate regression analysis. This approach has proven very successful in the past in explaining the economic impacts of climate policy at the national and international levels (Repetto and Austin, 1997; Barker et al., 2002; Barker and Jenkins, 2007).

The main results of our meta-analysis are presented in Table 4. Our dependent variable, the percent change in Gross Domestic Product/Gross State Product, is a continuous variable. All other independent variables are binary, taking a value of "1" if the assumption or causal factor was included in the analysis, and "0" otherwise. For example, *Positive Costs* takes a value of "1" if an official stakeholder group or engineering analysis indicates that the policy option will incur a direct positive cost (at the site of its implementation) on the state or national economy, and "0" if they indicate that it will incur a negative direct cost. One limitation is that only half of the studies actually listed the dollar cost or saving of the option(s) they analyzed, so this variable had to be coded as just positive or negative, which does not allow for as finely grained a delineation of the effect of this variable.

Note that for some studies we included the analysis of individual options, as well as the total package of options, typically a state or national climate action plan. Still, only a portion of the set of studies included all of the variable values, which limited the number of overall observations to 37.

Past meta studies (Barker et al., 2002; Barker and Jenkins, 2007) had nearly 50 times more observations than our meta-analysis. However, these past studies are spurious in providing causality between a model's assumptions and overall output because they rely on only a handful of studies and use all outputs from those studies (most of them just sensitivity test of the basic analysis) as separate observations in the meta-analysis. This leads to a disproportionate weighting between studies within the overall meta sample, to the degree that one or two studies can provide nearly 50 percent of all observations for the entire meta analysis. When this is the case, there is hardly any variability among regressors, because the assumptions of one or two studies become dominant throughout the entire sample.

Our selection method on the other hand, overcomes this problem. Despite the fact that our overall number of observations is fewer than past meta studies, it gives nearly equal weight to all studies, and independent variables are not skewed toward those studies that provide the largest percentage of the overall sample.

Our meta-analysis began with nearly 20 variables present in the studies that could be quantified as binary variables for estimation in the model. As is often the case, not all of those quantified variables were statistically significant, and in some cases, their presence caused issues of multi-collinearity. In statistical analyses, this problem exists when two or more variables are highly correlated with one another, and thereby bias the results of the analysis. As a result, simplifying changes in the estimating equation were necessary, and the method most appropriate was forward stepwise regression, which maximized statistical significance and explained variance, while minimizing collinearity.

Two models are presented in Table 4. Model 1 is the most parsimonious, a reduced-form model with four key explanatory variables. Each of the four variables is statistically significant at the 95% confidence level. The first regressor is a measure of *Total Costs or Savings* of a policy option or sum of options. It is determined exogenously by a collaborative stakeholder process, by cost-engineering data, or by some other process, and is usually not a direct calculation of the study. The variable takes a value of "1" if the policy option was identified to have a positive direct cost, and a value of "0" if the policy option was identified to incur a negative direct cost (savings).

Table 4. OLS Regression Analysis of Percent Change in GDP/GSP

	Model 1	**Model 2**
Positive Costs	-0.75*	-0.7*
	(-2.31)	(-2.23)
Substitution Effects	-0.81**	-0.40
	(-2.59)	(-1.31)
Nuclear	-1.54**	-1.56**
	(-3.84)	(-3.54)
Investment Addition	0.75*	0.67
	(2.13)	(1.92)
Offsetting Effects		-1.51**
		(-2.85)
Revenue Recycling		0.26
		(0.56)
Electricity Displacement		-0.12
		(-0.40)
Intercept	0.43	1.59
R^2	0.58	0.66
F-statistic	10.06**	7.41**

** $\alpha < 0.01$, * $\alpha < 0.05$, t-values in parentheses, based on White's robust standard errors.

causal factor was included in the analysis, and "0" otherwise. For example, *Positive Costs* takes a value of "1" if an official stakeholder group or engineering analysis indicates that the policy option will incur a direct positive cost (at the site of its implementation) on the state or national economy, and "0" if they indicate that it will incur a negative direct cost. One limitation is that fuels). *Investment Addition* is a binary regressor, which takes a value of "1" if the parameters of the study are such that, investment in GHG mitigation policies are additive to the economy. This parameter takes a value of "0" if they are assumed to displace existing investment. *Nuclear* is binary as well, and takes a value of "1" if the study includes nuclear as a policy option for meeting mitigation targets. Model 1 has relatively strong summary statistics as indicated by the coefficient of determination (R^2); the model explains almost 60 percent of the variance in economic impacts on GDP/GSP across all cases analyzed. The model also has a strong F-statistic, indicating that the model has included a proper set of independent variables.

The inference that can be drawn from Model 1 is that climate mitigation measures that are identified to be cost-incurring result in generally negative impacts to a state or national economy. On average, policy options that are assessed positive costs result in a ¾ percentage point decrease in GDP/GSP, holding all other variables constant at their mean. On the other hand, this also indicates that policy options identified as cost-saving achieve a direct positive impact of ¾ percent on GDP/GSP, on the average.

The other two coefficients of Model 1 pertain to modeling assumptions inherent to a study's macroeconomic analysis. On average, policy options from studies that include substitution effects produce a 0.81 percentage point decrease in GDP/GSP. On the other hand, policy options from studies that include investment addition as a modeling assumption lead to, on average, a ¾ percent increase in GDP/GSP. One inference that can be drawn from these results is that investment in climate mitigation technology, when additive to a state or national economy has a stimulating effect that, in studies analyzed, is almost large enough to overcome the costs associated with substituting toward more costly and less carbon-intensive forms of production.

Another inference that can be drawn from Model 1 is that the use of nuclear electricity generation in a state, regional or national mitigation policy can dramatically push the overall macroeconomic impacts in a negative direction. Studies of mitigation policies that include nuclear find on average, more than a 1.5 percent drop in GDP/GSP overall with the coefficient being highly significant. There are potentially two reasons for this. First, nuclear power is a relatively expensive policy option, and as such would otherwise be expected to raise costs and have a negative impact on a state's economy. Second, studies that commonly show negative impacts tend to include this option. Whereas the first reason is intuitive, our analysis also supports the second. Cross tabulation indicates that of the 37 observations in our analysis, 13 included nuclear. Of those 13, 10 cases were from observations that generated negative impacts.

5.2 Extended Form Statistical Model

Table 4 also provides the results of an extended form linear model. Model 2 includes three additional regressors, *Offsetting Effects, Revenue Recycling and Electricity Displacement.* These three are also binary regressors. Offsetting effects takes a value of "1" if these effects are included in the study. Revenue recycling takes a value of "1" if the model allows for tax or auction revenue generated from the policy option to be returned to ratepayers. Electricity displacement takes a value of "1" if the model allows for the displacement of generated electricity from neighboring states or across state lines.

The extended form model (Model 2) retains much of the same inference of the reduced form model. Three of the original four regressors remain roughly equivalent in magnitude and statistical significance, with the exception of *Substitution Effects*, which is suppressed in both magnitude and standard error. One possible cause for this is potential collinearity between added regressors of the extended form model and *Substitution Effects*. This was evaluated however, and there exists a small degree of collinearity between it and *Offsetting Effects* (ρ=0.42); however this was not of sufficient magnitude to warrant elimination from the model.

Offsetting Effects have a significant and negative impact on GDP/GSP (-1.51 percent) on the average, holding all other variables constant at their mean. As discussed above, offsetting effects can often have dampening impacts on the demand side. Revenue recycling on the other hand is positive but usually not significant. Intuitively, policy options that return GHG tax or GHG auction revenue to ratepayers will have less of a dampening impact than those that do not; however, only 6 (of 37) observations include revenue recycling, and 5 of those 6 observations also include offsetting effects[2]. Therefore, the coefficient is in the expected direction; however, it falls short of statistical significance because of characteristics inherent to the sample.

The coefficient for *Electricity Displacement* is also in the expected direction; however, it also falls short of statistical significance. Intuitively, the displacement of electricity across state lines constitutes leakage, and can have a dampening impact on a state's economy. It can also have a slight stimulating effect on a state's economy if imported electricity generates a savings because neighboring states use more efficient production or cheaper fuels. In that case, electricity displacement represents a cheap substitute and produces a savings. In our analysis there are a total of 27 policy options that allow for electricity displacement. Stakeholder groups identify 10 of those 27 (or 37%) to constitute cost-savings (negative costs). Because both of these competing effects occur simultaneously and differ by context (state by state, or region by region), this coefficient is not statistically significant.

6. Quantile Regression Analysis

The statistical analysis of climate impact studies provided here warrants further inquiry through alternative statistical models. Frequently the most parsimonious statistical model provides the greatest explanatory power, but scrutiny is warranted.

On occasion, researchers find themselves in the middle of intractable debates among dialectally opposed camps. We believe this to also be the case for economic analyses of climate mitigation policy. On one side, there are researchers who find that climate change mitigation policies are potentially damaging to economic output or employment because they minimize the economic incentives to utilize cheap fuels or production processes that are carbon and energy-intensive. On the other side, there are researchers who find that climate mitigation policies can be productive to an economy overall, because they can induce key capital investments, technological improvements, and more energy-efficient outcomes.

Because of this natural schism among researchers, meta-analytic methods should evaluate the sensitivity of impacts given the predisposition of the studies analyzed. To accomplish this, we employ quantile regression analysis. To date, no comprehensive meta-analysis of climate change mitigation policy includes this approach.

Quantile regression is similar to Ordinary Least Squares regression in that there is a continuous dependent variable evaluated asymptotically. However, rather than evaluate the impact on the mean of that dependent variable given parameter changes in the estimating equation, quantile models evaluate changes in the dependent variable at varying points on the distribution of the dependent variable (quantiles) within that dependent variable's range.

This allows us to evaluate the impact of macroeconomic assumptions on the full range of economic impacts within our dependent variable. We can now evaluate the impact of modeling assumptions (e.g. Investment Addition) on studies that find significant negative GDP/GSP impacts separately from those that find significant positive GDP/GSP impacts. This means that we can evaluate the impact of investment addition on studies within the 95th percentile (or any other) of GDP/GSP impacts, and not be limited to inference based on the "mean" climate economic impact analysis of the ordinary approach.

For the sake of equivalence and comparison, we evaluate Models 1 and 2 via quantile regression. The reduced form model (Model 1) is given by:

$Q_\tau(\%\Delta GDP/GSP) = \alpha + \beta_1(Positive\ Costs) + \beta_2(Substitution\ Effects) + \beta_3(Nuclear) + \beta_4(Investment\ Addition) + \varepsilon$. The extended form model (Model 2) is given by: $Q_\tau(\%\Delta GDP/GSP) = \alpha + \beta_1(Positive\ Costs) + \beta_2(Substitution\ Effects) + \beta_3(Nuclear) + \beta_4(Investment\ Addition) + \beta_5(Offsetting\ Effects) + \beta_6(Revenue\ Recycling) + \beta_7(Electricity\ Displacement) + \varepsilon$.

The quantiles that we evaluate are τ = (0.5, 0.25, 0.5, 0.75, 0.95), or the 5th, 25th, median, 75th and 95th quantiles, respectively.[3] Our results were produced using R-project software (Koenker 2010).

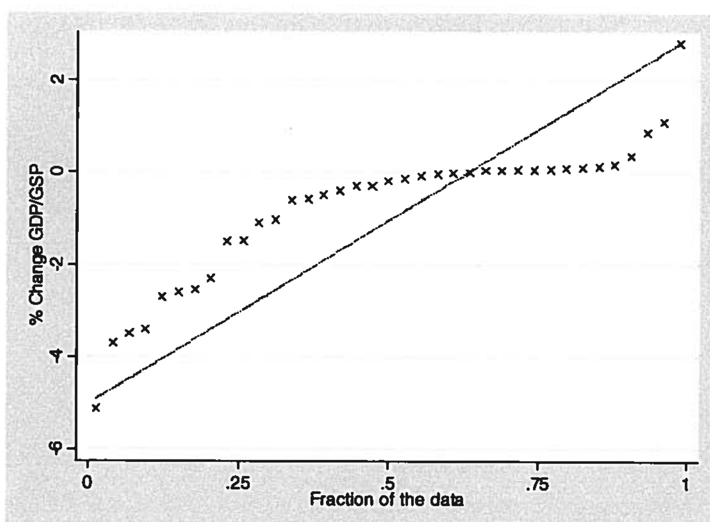

Figure 2. Quantile Plot of Percent Change in GDP/GSP

The OLS models provided in Section 5, are more sensitive to outlying observations (e.g., BHI, 2008; McKinsey, 2009). OLS regression is, in general, more sensitive to outliers than median quantile regression (τ=0.5), because OLS minimizes the sum of squared residuals, whereas median quantile regression minimizes the sum of absolute residuals. Figure 2 above provides a quantile plot of our dependent variable. OLS regression would tend to sample less heavily those observations along the intersection point-- about the 65th percentile.

Table 5 provides the results for both the reduced and extended form quantile models. The standard error estimation method for quantile models in R is typically considered to be more accurate than in competing statistical software packages. Note that the estimation of our models in Stata 10 yielded smaller standard errors and larger t-values for most coefficients and most τ parameters.

The variable *Positive Costs* is roughly equivalent in magnitude and significance to both OLS models, at most quantiles. In both the reduced and extended form models, *Positive Costs* have the largest and most statistically significant impact on extreme quantiles (τ=0.5 and 0.95). This indicates that climate change mitigation policies that are assessed positive costs by stakeholder groups are less likely to result in negative macroeconomic impacts for studies that find little to no change in the macroeconomy. This is intuitive. However, what is less intuitive is why this coefficient remains large and significant at higher quantiles. The inference that can be drawn from this is: some of those studies that generally find positive macroeconomic impacts from climate mitigation policies still yield negative macro impacts from positive cost policy options. This would tend to lend credence to those studies that have found overall positive macroeconomic impacts, as this shows that their analyses are consistent with stakeholder assessments but also conscientious to the fact not all policy options will result in positive macro impacts.

On the other hand, the variable *Nuclear*, which is consistently negative, tends to be most statistically significant and largest in magnitude at the lowest quantiles. When included in a climate change mitigation policy, it is intuitive that nuclear electricity generation is a costly policy option, mainly due to the liability and regulatory costs associated with its implementation. The fact that it is large in magnitude and statistical significance for those studies that assess largely negative macroeconomic impacts would tend to lend credence to those studies that typically assess negative macroeconomic impacts. On the whole, those studies tend to favor nuclear generation as a policy option, but they still attribute large negative macroeconomic impacts to nuclear policy options. If the coefficients for *Nuclear* were significant at the 95th quantile, it would suggest that those studies that assess overall positive economic impacts are most amenable to nuclear policy options. Although this is highly counterintuitive, the opposite, which is equally counterintuitive, is affirmed by these results: those studies that assess overall negative economic impacts are least amenable to nuclear electricity generation.

Evaluation of the coefficients for *Investment Addition* is also insightful. The quantile regression results suggest that investment addition has the most significant and positive impact for those studies that result in the most negative macroeconomic impacts. As mentioned above, the impact from additive investment can go either way, because of its potential reciprocal relationship with consumption. Additive investments that lead to efficiency gains that have dampening effects on the economy (e.g., lower demand for electricity or fuel) can still lead to increased consumption in other sectors (e.g., building retrofits). It would seem, therefore, that the assumption of investment addition has its most positive macroeconomic impact where the most negative macroeconomic impacts are found. Its coefficient is both large and robust about the lowest quantiles.

As discussed in Section 5 above, *Offsetting Effects* can also have both a positive and a negative impact on the study's overall assessment. These effects have the most robust negative impacts on studies within the lowest quantiles, although they have robust negative impacts at nearly all quantiles. Also of note, *Revenue Recycling* and *Electricity Displacement* carry the expected sign in all but the lower quantiles. Although short of statistical significance, these coefficients suggest that, where positive macroeconomic impacts are found, revenue returned to consumers and ratepayers has a neutral or stimulating effect on the economy. They also suggest that, where positive macroeconomic impacts are found, the displacement of in-state electricity generation does not have a stimulus effect.

7. The Effect of Modeling Structure and Assumptions on Results

To illustrate the effect of macroeconomic modeling approaches, data, assumptions, linkages, and macro impact results, we will elaborate on two key studies contained within this meta-analysis. One study yields negative impacts of climate change policy on the macroeconomy, and the other yields some positive impacts. CRA International, under the authorship of David Montgomery et al. (2009), performs the first of these studies. The study examines the effect of the Waxman-Markey American Clean Energy and Security Act of 2009 (ACESA or H.R. 2454). It makes use of CRA's multi-regional model of the U.S. known as the Multi-Sector, Multi-Region Trade Model (MS-MRT), the Multi-Regional National Model (MRN), and the North American Electricity and Environment Model (NEEM). The first model is basically a combined CGE/econometric model, the second a multi-regional CGE model with international linkages, and the third an electricity sector, technology-specific model. The first two models have gone through significant peer review and are considered among the leaders in the field. Any criticism of the results therefore must rest more on the data and assumptions used and the manner in which macro linkages are specified.

Although the authors do perform sensitivity analyses, their basic energy data base projections are highly dependent on the U.S. Energy Information Administration (EIA), which has traditionally been considered to perform relatively pessimistic evaluations of energy efficiency and renewable technologies. In addition, the analysts note some of the duplicative aspects of the Waxman-Markey Bill that would likely increase its compliance costs.

Such findings are thus likely to call for greater scrutiny and a streamlining of what causes unnecessary expenditures. The model essentially includes all of the major macro linkages. However, assumptions relating to some of them are extreme, especially one on the crowding-out effect of investment in mitigation and sequestration. The authors are also critical of the cap and trade approach to implementing much of the legislation because it raises more uncertainty about the future costs than would a carbon tax. An indication of the pessimistic nature of the key data

Table 5. Quantile Regression Analysis – Percent Change in GDP/GSP

	Model 1					Model 2				
Positive Costs	-0.56**	-0.58	-0.35	-0.26	-0.82**	-1.61**	-0.58*	-0.26	-0.29	-0.82**
	(-2.98)	(*2.42)	(-0.93)	(-0.51)	(-2.66)	(-5.25)	(-2.07)	(-0.89)	(-1.70)	(-4.11)
Substitution Effects	-0.04	-0.13	-0.81**	-0.57	-2.05**	0.01	-0.13	-0.21	-0.21	-0.21
	(-0.21)	(-0.54)	(-2.11)	(-1.11)	(-6.63)	(0.02)	(-0.42)	(-0.66)	(-1.12)	(-0.95)
Nuclear	-2.58**	-2.24	-1.46**	-1.10*	-0.04	-2.97**	-2.24**	-1.90**	-1.20**	-0.05
	(-13.79)	(-9.58)	(-3.89)	(-2.20)	(-0.15)	(-8.64)	(-7.27)	(-5.94)	(-6.43)	(-0.21)
Investment Addition	1.93**	0.55	0.54	0.49	0.17	0.63*	0.55*	-0.02	0.14	0.05**
	(10.81)	(2.47)	(1.50)	(1.04)	(0.60)	(2.11)	(2.01)	(-0.08)	(0.86)	(2.52)
Offsetting Effects						-3.01**	-1.58**	-1.98**	-2.28**	-1.71**
						(-5.05)	(-2.92)	(-3.52)	(-6.92)	(-4.39)
Revenue Recycling						-0.05	-0.09	0.10	0.10	0.10
						(-0.12)	(-0.27)	(0.26)	(0.46)	(0.38)
Electricity Displacement						0.34	0.01	-0.23	-0.32	-0.36
						(0.96)	(0.03)	(-0.68)	(-1.61)	(-1.52)
Intercept	-1.93**	-0.45	0.32	0.43	2.80**	2.07**	1.12**	2.28**	2.70**	2.70**
	(-9.58)	(-1.85)	(0.83)	(0.82)	(8.83)	(3.55)	(2.13)	(4.15)	(8.39)	(7.09)
τ	0.05	0.25	0.5	0.75	0.95	0.05	0.25	0.5	0.75	0.95

** $\alpha < 0.01$, * $\alpha < 0.05$, t-values in parentheses. Model results produced using Project R software (Koenker, 2010).

input to the model is the CRA projection of the allowance price of \$124/metric ton CO_2e in the year 2050.

Another study of the impacts of mitigation policy by Hanson and Laitner (2006), which uses Argonne National Laboratory's excellent AMIGA model, a state of the art computable general equilibrium model of 21 world regions, to analyze the impact of refining technology policy to reduce the investment requirements of meeting long-term climate stabilization goals. The model is based on an extensive and detailed analysis of individual technologies in relation to U.S. EPA studies. Again, it should be noted that EPA estimates are traditionally considered more optimistic about the future costs of renewables and energy efficiency. The analysis focuses on issues of investment levels and displacement, and how technology policy and mitigation policy design can lower investment requirements to a very low level and can mute negative impacts on GDP, so that they are trivial, and in some cases even positive. Thus, two excellent models of very similar forms yield disparate results. The explanation must fall on differences in data inputs and assumptions, including those that affect model parameter values.[4,5]

8. Conclusions

Climate change mitigation policies, such as cap-and-trade, carbon taxation, renewable portfolio standards (RPS), corporate average fuel economy standards (CAFE), low-carbon fuel standards, aforestation measures, etc., are hotly contested within both the scholarly and policy communities. Given this divergence, this paper has provided a meta-analytic approach to a comprehensive sample of climate mitigation studies, to identify how data inputs, assumptions, and causal mechanisms affect their outcomes. Key macroeconomic linkages were identified throughout the sample of studies that explain how two (or more) macroeconomic analyses of comparable policies can lead to fundamentally different predictions for the impact of those policies. This paper also elaborated on the modeling methodologies used across our meta sample, and how different macroeconomic modeling approaches (I-O, CGE, and ME) can lead to fundamentally different results because of the differences between microeconomic foundations of macroeconomic relationships.

This paper has also spoken to the divide that exists among scholars of climate mitigation policy. On one side, climate mitigation measures are said to be ultimately damaging to the macroeconomy because of their elimination of cheap fuels or negative externalities in production processes. On the other side, climate mitigation measures are said to promote a more productive macroeconomy, because they can induce key capital investments, technological improvements, and energy-efficiency. A quantile regression analysis of a comprehensive meta sample was performed, that highlights the nature of those assumptions and economic linkages across this ideological divide.

Several key findings were provided. Those mitigation measures that are identified by stakeholder working groups or cost-engineering reports as cost incurring (positive cost) policies lead to an average impact of ¾ percent reduction in GDP/GSP. These impacts become most extreme at both ends of the ideological divide. Key economic linkages such as substitution and offsetting effects, and investment addition were also evaluated. While investment addition has an overall positive macroeconomic impact across all studies, its affects are most profound on those studies that assess negative macroeconomic impacts. And, nuclear power, which is typically a high cost option, has its least negative impacts for those studies that find economic benefits in climate mitigation measures.

It is important to note that one should not dismiss the findings of this paper as simply stating the fact that assumptions drive results. Assumptions do ultimately have a significant impact on results in macroeconomic impact studies; however, this paper has shown that those assumptions often work in counterintuitive ways. Those economic assumptions that would otherwise drive the most negative findings are often most key for those studies that reach the most optimistic conclusions. And, the opposite is sometimes true. Moreover, our analysis has identified the extent to which some assumptions are relatively much more important than others in driving results.

ENDNOTES

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[1] In sophisticated models, these impacts are referred to as general-equilibrium or macroeconomic effects.

[2] Most studies are vague about the use of tax or auction revenues. Clearly recycling (whether in terms of lump sum transfers or tax reduction) is more stimulating in the short-run than is the use of these revenues for deficit reduction.

[3] See Koenker and Bassett (1978), Koenker and Hallock (2001) and Koenker (2005) for detailed descriptions of quantile regression models.

[4] Note that some study results are due to the severe limitations of less sophisticated models, such as input-output analysis. For example, Chamberlain's (2009) analysis does not allow offsetting effects to the cost increasing effect of mitigation options, such as the fact that any dampening effect will lower prices, thus causing some rebound in the economy. This is similarly the case in I-O studies that indicate a positive impact of climate mitigation policy on the macro economy, such as Pollin et al. (2009), which exclude offsetting effects that might somewhat offset these impacts.

[5] Other studies yield some important insights into the importance of individual state conditions, such as whether a state is a major coal producer or importer. Rose and Wei (2006) analyzed the impacts of the displacement of coal-fired electricity generation by a combination of a 20 percent renewable portfolio standard (RPS) and a shift to natural gas-fired generation on the economies of each of the 48 continental states. The analysis was restricted in that it analyzed high levels of coal-fired displacement of 33 percent and 67 percent. Moreover, it assumed that the RPS mix projected for 2015 was an extrapolation from each state's conditions at the time of the writing, rather at a least-cost mix. In addition, gas prices were based on EIA estimates. Even with these data and assumptions that push the results toward negative macro impacts, the report did identify ten states for which the move away from coal-fired generation would yield overall positive macroeconomic outcomes. The distinguishing characteristic was not surprising: major coal producing states typically were projected to lose, while states that do not have any coal mining jobs to lose and for which geographic conditions favored renewables like solar and wind stood to gain. We could not enter the "coal state" variable into our meta-analysis below because several jurisdictions in the various studies could not readily be labeled as "coal" versus "non-coal" (e.g., the Susquehanna River Basin and the U.S. as a whole).

REFERENCES

Barker, T., and K. Jenkins. 2007. The Costs of Avoiding Dangerous Climate Change: Estimates Derived from a Meta-Analysis of the Literature. United Nations Human Development Report 2007/2008.

Barker, T., J. Kohler and M. Villena. 2002. Costs of Greenhouse Gas Abatement: Meta-Analysis of Post-SRES Mitigation Scenarios. *Environmental Economics and Policy Studies* 5: 135-166.

Bezdek, R., and R. Wendling. 2003. Potential Long-term Impacts of Changes in US Vehicle Fuel Efficiency Standards. *Energy Policy* 33:407-419.

Borenstein, M., L.V. Hedges, J.Higgins and H.R. Rothstein. 2009. *Introduction to Meta-Analysis*. West Sussex, UK: John Wiley and Sons.

Chamberlain, A. 2009. *Who Pays for Climate Policy? New Estimates of the Household Burden and Economic Impact of a US Cap-and-Trade System.* Tax Foundation Working Paper #6.

Electric Reliability Council of Texas. *Analysis of Potential Impacts of CO2 Emissions Limits on Electric Power Costs in the ERCOT Region.* May, 2009. Prepared for the Public Utility Commission of Texas.

Granade, H.C. et al. 2009. *Unlocking Energy Efficiency in the U.S. Economy*. McKinsey Global Energy and Materials.

Greene, D.L., and J.R. Kahn, R.C. Gibson. 1999. Fuel Economy Rebound Effect for U.S. Household Vehicles. *Energy Journal* 20(3): 1-31.

Hanson, K. and J. Laitner. 2006. Technology Policy and World Greenhouse Gas Emissions in the AMIGA Model. *Energy Journal* 27: 355-71.

Koenker, R.. 2005. *Quantile Regression*. Cambridge University Press. New York, NY.

Koenker, R. and G. Bassett. 1978. Regression Quantiles. *Econometrica* 46: 33-50.

Koenker, R. and K.F. Hallock. 2001. Quantile Regression. *Journal of Economic Perspectives* 15(4): 143-156.

Koenker, R. 2010. Quantreg: Quantile Regression Package for R-Project Software. Available at: http://cran.r-project.org/web/packages/quantreg/index.html

Lipsey, M.W. and D.B. Wilson. 2001. *Practical Meta-analysis.* Sage Publications. Thousand Oaks, CA.

Maggioni, E. 2008. *The Rebound Effect: Summary of Findings.* School of Policy, Planning and Development, USC, Los Angeles, California.

Management Information Services, Inc. 2008a. *Potential Impact of Florida's Greenhouse Gas Reduction Mandates in North Carolina on the State's Economy, Jobs, and Industry.* Prepared for American Coalition for Clean Coal Electricity.

Management Information Services, Inc. 2008b. *Potential Impact of South Carolina's Greenhouse Gas Reduction Plan on that State's Economy and Jobs.* Prepared for American Coalition for Clean Coal Electricity.

Minnesota IMPLAN Group (MIG). 2010. http://www.implan.com

Montgomery, W.D. et al. 2007. *Economic Analysis of Florida's Executive Order 07-127.* Charles Rivers Associates. Prepared for Florida Chamber of Commerce and U.S. Chamber of Commerce.

Montgomery, W.D. et al. 2009. *Impact on the Economy of the Clean Energy and Security Act of 2009 (H.R. 2454).* Charles Rivers Associates. Prepared for the National Black Chamber of Commerce.

Oladosu, G. and A. Rose. 2007. Income distribution impacts of climate change mitigation policy in the Susquehanna River Basin Economy. *Energy Economics* 29: 520-544.

Paltsev, S., J.M. Reilly, H. D. Jacoby and J.F. Morris. 2009. *The Cost of Climate Policy in the United States.* MIT Joint Program on the Science and Policy of Global Change, Report No. 173.

Pollin, R., Henitz, J., and Garrett-Peltier, H. 2009. *The Economic Benefits of Investing in Clean Energy.* Department of Economics and Political Economy Research Institute, University of Massachusetts, Amherst.

Ponder, D. J. Tiller and J. Hoyle. 2008. *Secondary Economic Impact Analysis of Greenhouse Gas Mitigation Options for North Carolina.* Prepared for the Center for Climate Strategies. The Appalachian State University Energy Center.

Repetto, R., and D. Austin. 1997. *The Costs of Climate Protection: A Guide for the Perplexed.* Washington, DC: World Resources Institute.

Roland-Holst, D. and Karhl, F. 2009. *The Florida Economy and a Federal Carbon Cap: Aquantitative Analysis.* Department of Agricultural and Resources Economics Working Paper, University of California, Berkeley.

Rose, A. 1996. Input-Output Economics and Computable General Equilibrium Models. *Structural Change and Economic Dynamics* 6: 295-304.

Rose, A. and D. Wei. 2006. *The Economic Impacts of Coal Utilization and Displacement in the Continental United States, 2015.* The Pennsylvania State University, University Park, PA.

Rose, A. and Wei, D. 2010. "The Economic Impact of the Florida Energy and Climate Change Action Plan on the State's Economy," *Climate Policy,* forthcoming.

Rose, A. and W. Miernyk. 1989. Input-Output Analysis: The First Fifty Years. *Economic Systems Research* 1(2): 229-271.

Ross, M. et al. 2008. *State-level Economic Impacts of a National Climate Change Policy.* Pew Center on Global Climate Change. White Paper.

Science Applications International Corporation (SAIC) 2008. *Analysis of The Lieberman-Warner Climate Security Act (S.2191) Using The National Energy Modeling System (NEMS/ACCF/NAM).* Report produced for the American Council for Capital Formation and the National Association of Manufacturers.

Tuerck, D. et al. 2009. *The Economics of Climate Change Legislation in North Carolina.* The Beacon Hill Institute at Suffolk University.

Tuerck, D. et al. 2008. *The Economics of Climate Change: Proposals in South Carolina.* The South Carolina Policy Council in cooperation with The Beacon Hill Institute, Suffolk University.