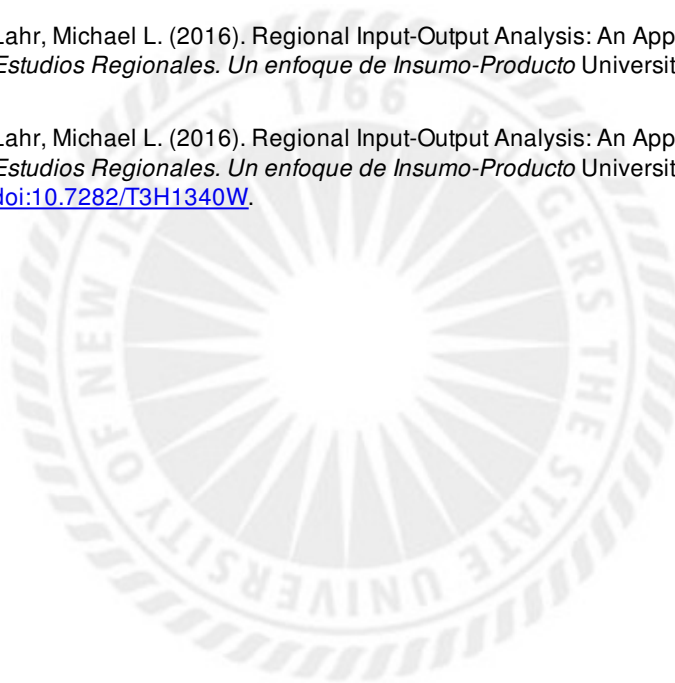


Regional Input-Output Analysis: An Appraisal of an Imperfect World

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Regional Input-Output Analysis: An Appraisal of an Imperfect World

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ABSTRACT. In the last retrospective on regional input-output analysis, Hewings and Jensen (1988) set out a set of emerging challenges. This paper generally examines how those challenges have been met in the intervening 25 years (plus some). A feature of this endeavor is to help young scholars identify research directions. In this vein, along the way I point out avenues that could be pursued. I conclude by identifying topics in input-output analysis that are currently hot and those that are not.

Introduction

The title of this paper purposely recalls a 1955 book entitled *Input-Output: An Appraisal*, which reported proceedings of a workshop designed to take stock of our field, which was then very young. It is now 60 years later. It is only because I prefer a focus on subnational input-output analysis that I decided to add the notion of an “imperfect world.” It is “imperfect” because all too often the data that we regional analysts have at our disposal are less in frequency and quality than what we would prefer. This not only deters us from working on many topics that other input-output analysts work upon: it also means we sometimes have to get rather clever when it comes to using the little data that we have at our disposal.

I am writing this paper with thoughts that it will help my young colleagues. And while our world is ever-changing, in writing this piece, I assumed that the present set of incentives that motivate academics—funding and publication impact factors—will remain in place for some time. I also hope that my young colleagues are at least as learned in matrix algebra as I have become. Consequently, I start my discussions by reminiscing wistfully about some of the early days our field, some of which took place even *before* I was born. I let the narrative lean on policy topics, such as climate change, international trade, and the north-south divide, that are likely to guide the direction our field for another 10-20 years. The paper’s outline is follows challenges set out by leaders in our subfield as I was writing my Ph.D. dissertation 25 years or more ago. In this vein, I note the changing nature of our field toward policy perspectives and away from new theory and methods. While I understand the importance of that change, I also lament that evolutionary track. Hence, I take extra effort to point out where the introduction of new techniques could be fruitful. I also intend to pinpoint some published pieces that are promising stepping stones works. Of course, I also identify some topics that appear to have reached a dead end, at least given present perspectives. Regardless, I hope that material herein will reinvigorate work in some hopeful and, yet, seemingly forgotten topics. Of course, this paper will undoubtedly also underline some areas that should continue to be our bread and butter.

Background. While Leontief’s (1941) work arguably the start of all things input-output related,¹ numeric storage set the stage to make his vision a reality. As Hotelling (1949) reports it

¹ His work has been compared to that of predecessors François Quesnay, Karl Marx, Léon Walras, and Ladislaus von Bortkiewicz. Moreover, according to Neisser (1941), young Leontief apparently used a mechanical calculating device for his computations that was constructed by MIT Professor John Wilbur, which could solve up to *nine* simultaneous linear equations with what was then deemed high accuracy. The machine, which weighed more than a ton, had on the order of 13,000 parts including 600 feet of steel tape and 1,000 ball-bearing pulleys.

The first utilization of number-storage for matrix calculation seems to have been in a machine reported in 1925 by Clark L. Hull. Punched tapes were used in conjunction with a device attached to a calculator. The machine read the numbers by poking steel fingers through the holes. While a sum of products was being formed, the operator could go out to lunch, leaving the machine alone in a locked room to stop itself at the conclusion of the operation. ... Hollerith cards are capable of carrying as many as ninety variates on a card. With suitable equipment the product of any two of these variates can be formed, summed over a large number of cards at very high speed, and presented simultaneously on dials, in print, and in the form of other card punches.... But the formation of inverses or principal components is of another order of difficulty, and Hollerith-type machines do not appear to lend themselves readily to direct determinations of these. We must therefore look to other types of mechanical and electrical aids, which, however, may be supplemented by ready matrix multiplication with punched cards or tapes.

Hotelling is telling us that the demands of calculating an inverse of anything but a very small matrix were problematic as the computer era got underway in the second half of the twentieth century. Many efforts got underway to make even machine-based calculations less time-consuming and, hence, cost-effective. One was matrix partitioning, for which Waugh and Dwyer (1945) and Hotelling, among others, appear to have founded. A second was based on examining the sensitivity of an inverse to numerical errors in its parent matrix. This stream of literature was started by Sherman and Morrison (1949, 1950) and Woodbury (1950) and more or less culminated with Dwyer and Waugh (1953) and Evans (1954) as well as Maaß (1980). A third exploited power series estimation and requires explicit Leontief matrix structure (Waugh, 1950; Holley, 1954; Evans, 1956; Berger and Saibel, 1957). An important motivation for this last thrust, according to Stevens (1990), is that a mere series of matrix-vector multiplications (and summations of them) is needed to perform impact analyses. Moreover, Miller and Blair (2009, p. 34) demonstrate that by about the seventh term of the power series, any subsequent term is quite small. This suggests that, while lacking perfect accuracy, truncation of the series sum is unlikely to matter much if some unknown amount of error exists in either the parent matrix or the final demand change for which an impact is being measured.

Sadly, this literature is all but forgotten in the wake of the nearly limitless desk- and lap-top computer power that we have had at our disposal during the past 30 years. With some fear of sounding like an old curmudgeon, I bemoan the educational loss to newer generations of students in our field because this literature contains a critical understanding of the mathematical limits of input-output economics. Some members of my generation of analysts learned matrix partitioning in order to understand hypothetical extraction approaches (Miller and Lahr, 2001), which were reappearing after their developments in the mid-1960s. We learned about Sherman and Morrison (1950) and its offspring so we could identify how sensitive the Leontief inverse might be to sectoral shifts and to learn which cells and sectors should be checked first during updating procedures in national and regional accounts. And as we started working with multiregional tables, a few of us (e.g., Robison and Gneiting, 1999) found that as late as the year 2000 the power-series approach was the only computationally manageable approach when estimating economic impacts on a very high-powered personal computer for an economic system with 30 or more regions with extreme sectoral detail (400 to 500 industries per region). It certainly helped to know as Stevens (1990) related that the so-called “round by round” approach reduced the number of floating point operations to less 2.87 percent (about a 35:1 ratio) of the levels required by brute-force inversion. Now that ample amounts of read-only memory (ROM) and 64-bit processing are available, however, even spreadsheet software like Microsoft’s Excel™ can handle nearly any imaginable matrix calculations. The shift in conference paper topics over the past 30

years reflects a more policy-oriented tilt.² The several panels of international input-output tables developed during the past years (see Tukker and Dietzenbacher, 2013 for an overview) assure that the tilt in topics will continue for a while. But change is not all bad. Whereas prospects for input-output analysts looked fairly bleak at the turn of the millennium, they are now about as strong as they have ever been.

About 25 years ago the divide between the Leontief and Isard camps of input-output analysis was rather stark. Students of Leontief were concerned with how technological change would affect labor. So they delved into the intraindustry distribution of firm size, divisions of labor, the speed of technology change, and, hence, interindustry dynamics. Meanwhile, Isard's students became concerned about how to build a better mousetrap, as information in national accounts did not appear to apply well to regional sub-economies of larger nations. More broadly, we were interested regional economies and, hence, spatial disaggregation of national accounts. Hence, more than a few of us got bogged down in technical aspects of the construction of regional and interregional accounts. In essence, we became interested in optimizing the use of the meager regional data that are available. A key focus was the nature of technology and trade as they spread across space, instead of across time. Spatial aggregation became our nemesis, and its evil twin, sectoral aggregation, was soon realized to be no friend either. Despite the differences, there was a good deal of common ground between the two I-O camps. The future of the world was the unifying element. Changes in trade and technology, as their effects on the environment and developing economies were common foci.

In 1986 the International Input-Output Association formed. A key element, besides its conferences which had been held for many years prior, was a journal just for us—*Economic Systems Research*! The added sharing of research via this single forum broadened perspectives for many of us. Regionalists, who had largely lost sight of the broader set for input-output table uses, now could re-learn them. National statistical offices gained insight from some technical tricks used by regionalists. They reciprocated and, at least temporarily, permitted some regional analysts access to some microdata from economic censuses. And national analysts became evermore focused on the prospects of producing a world input-output table to give global climate change initiatives a lift. In essence, the existence of a journal for input-output analysts demonstrated others, as well as us, that the field was still alive and well. It also enabled the field to regain some lost relations—those who work on social accounting matrices, computable general equilibrium models, and systems econometric time-series models. And, somewhere among all of this clamor, engineers interested in life-cycle costing threw in their lots with us as well.

An Appraisal of Input-Output Analysis Since 1988.

So, what's been going of late in the world of input-output analysis? Materially, we have mostly addressed the set of "emerging challenges" identified by Hewings and Jensen (1988). They are:

- 1) Using input-output analysis to expand growth theory.
- 2) Rapid growth in adoption of input-output analysis for planning, forecasting and general impact analyses, especially in developing countries;

² In fact, the International Input-Output Association renamed its "International Conference on Input-Output Techniques" to the "International Input-Output Conference" somewhere around 2009 to help broaden its prospects.

- 3) Rise in the integration of I-O models with other mathematical economic models, plus more sophisticated balancing techniques; and
- 4) Decline in attention in the production of survey-based regional input-output tables and movement toward development of hybrid input-output tables:
 - a. New attention to the notion of key sectors and
 - b. Returned attention to the sensitivity of I-O structures to error/bias.

I add to this list that we have also come to understand that very disaggregated input-output tables and social accounting matrices are generally preferred to more aggregated ones. This last holds special importance in the wake Lucas's (1976) conjecture that it is naive to predict the effects of a change in economic policy entirely on the basis of relationships observed in historical data, which while focused on systems econometric time series models, especially very industrially disaggregate ones, has also spilled over into critiques of other macroeconomic tools like input-output and computable general equilibrium models.

Interindustry Growth Models.

Of these the most pleasing and, in many ways, exciting development for me has been the movement of interindustry structures into growth theory—item 1) above. The others more or less have been extensions of applied research that both Hewings and Jensen started to undertake at the time of their overview.³ In essence, interindustry growth theory literature is founded on Rosenstein-Rodan (1943), Nurkse (1952), Scitovsky (1954), Hirschman (1958), and Kremer (1993) who focus on economic complementarity of industrial technology and linkages. I will not review the full set of literature here. Instead, I present enough to show that, as a trend, this literature runs against Lucas's conjecture that presses for more aggregate analyses and toward investigations that are industrywise more disaggregated. For example, a fairly early piece by Ciccoine (2002) shows that when industrial technologies are adopted throughout intermediate-input chains of an economy, they tend to use intermediate inputs more intensively compared to the technologies they replace. In the vein of Schumpeter's (1942) concept of creative destruction, Ciccoine therefore suggests that industrial progress can have large positive effects on aggregate income and productivity even when returns to scale for establishments are fairly meager. And while Jones (2011) shows formally the well-known principle that as intermediate goods enhance their shares of gross output, an economy's output multiplier rises, he also demonstrates that distortions due to enhanced use of transportation services can reduce output. His work implies that rising costs in transportation services will therefore lead to reduced output in transportation services itself and thereby potentially cause a vicious downward spiral in intermediate goods production. Acemoglu et al. (2012) show that an economy's rate of aggregate volatility decays more quickly when the structure of the network defining the economy's linkages is weaker; that is, volatility has less to do with an economy's industrial diversity than with the interindustry interdependence. Clearly, from the brief sample reviewed above, it should be clear that, in part, this relatively new genre of growth theory has begun by demonstrating in formal fashion some things that empiricists already "know." But it does so in a way that also should please Lucas's protagonists in that it does not lean on historical trends. In any case, since greater insight into

³ Indeed, Hewings has largely lead the charge of his REAL (Regional Economics Analysis Laboratory) mafia in tending to many of the above initiatives.

economic development principles is likely to stem from extensions of the existing literature on interindustry growth theory, its evolution over the next decade or two should be quite exciting!

Expansion in the Use of I-O Worldwide.

Generally speaking, as countries develop, they escalate the amount of data available from their official statistical systems. Data availability via Brazil's national statistical office, for example, has become a model for the entire the world. And within China, input-output data are among the best macroeconomic data available at both national and provincial levels. Moreover United Nations (U.N.) efforts toward standardizing national accounts have encouraged many countries to develop input-output tables. In the absence of time series with sufficient duration on key macroeconomic indicators, input-output tables are often the only tool available in developing countries that can be used to facilitate some degree of economic planning. As a result, countries like Nepal and the Philippines lean heavily on input-output models when examining national development planning alternatives. China does as well, but it is able to work with a set of multiregional tables as well.

In fact, to gain a better global environmental and trade perspective, several multiregional international input-output databases have been developed (Tukker and Dietzenbacher, 2013), as was mentioned earlier in this piece. The EORA database, in particular, is noteworthy for including estimates of national accounts for countries that have not produced a set of input-output tables for decades (e.g., Argentina), if ever (e.g., Haiti). Clearly the EORA data represent the extreme of the movement away from using primary data to produce input-output accounts. The researchers involved (Lenzen et al. 2013, p. 39) tell us that they focus “on standardisation, automation, and advance computation” to achieve “labour and cost savings.” But they report (p. 39) that the accuracy of results of research derived from their database “depend on the research question. Results will generally be uncertain at the sectoral level and for small sectors, but not necessarily uncertain for small countries, especially not for small countries with high-quality IO data.” This of course, begs questions about the reliability of EORA I-O and trade accounts for those countries that do not have recent I-O data of high quality (say, e.g., Argentina and Haiti). They can only be as good as the quantity and quality of the source data employed in their production (statistical data on the country as published by the U.N. and the input-output technology of some similar economy as determined by the EORA team). Perhaps in due to the extreme lack of superior data in their approach, EORA reports a variety of reliability statistics for their data (Hewings and Jensen, 1988, called this “error bias”). In essence while an analysis of Haiti's economy using EORA I-O data might be less reliable than one might hope, it will certainly be better than what one can otherwise achieve. In fact, until Haiti undertakes a census of industry to create its own table, how can one ever know how “bad” or “good” EORA's estimate of it might be? Needless to say, this calls for some research. Now, I have centered my focus on EORA, mostly because it includes data for more countries than any other world MRIO databases now available; but related research questions can be investigated with the others. In fact, as long as researchers keep an eye on the relative strengths and weaknesses of these databases, they should be tapped as data sources for what they were intended—research on international economic issues. To date they are sorely underused on this count

Integration of I-O with Other Techniques.

CGE models. As input-output tables proliferated around the globe, the notion of a stylized Walrasian computable general equilibrium (CGE) models with nonfixed prices took hold

following the work of Scarf (1969). Two of his students, Shoven and Walley (1972), were the first to demonstrate the policy value of Scarf's approach when they investigated whether it was better for the United States to enhance tax rates on labor income or capital gains. In essence CGE models alter some of conceptual rigidities that Leontief's was compelled to add in order to make Walras's work (1898) an empirical reality. A main feature is that, compared to I-O models, CGE models add some flexibility to production functions by permitting some substitution among commodities—at least among factors of production—through theoretically justified market-clearing conditions that enable prices to vary relative to one another. Of course, a key element in CGE models, which employ mathematical programming techniques, is that households seek to maximize their utilities and firms opt to maximize profits. This assumed optimizing behavior in conjunction with greater flexibility in production functions and a disturbance (or shock) to the modeled economy forces changes in the supplies and demands of inputs, including factors of production, which in turn alter the relative prices of inputs. By comparing the new computer equilibrium conditions to those of the baseline (prior or original), one can then get some insight into the how the exogenous disturbance might would the affect the economy, given the assumptions inherent to the CGE model.

Hewings and Jensen (1988) foresaw the oncoming wave of CGE modeling at a regional level of analysis. Indeed, nowadays several vendors of CGE software exist that provide related educational services (e.g., the Centre for Policy Studies at Victoria University [CoPS], the Global Trade Analysis Project at Purdue University [GTAP], and the EcoMod network) and are now used regularly by the likes of the World Bank and the Inter-American Development Bank. Some practitioners militate against use of such canned software, particularly those analysts not versatile in the programming language and inner workings of a CGE model. This is because, as the use of such models has progressed, the foibles of such models have become clearer. Thus, tests of the sensitivity of model outcomes to variations in the key parameters (e.g., elasticities among the factors and other inputs) and different closure rules (e.g., Rose, Hanson, and Li, 2001) have become standard fare in the conduct of CGE analyses.

Toward Frame-Shifting. A posthumously published piece by my friend and colleague Philip Israelevich (2002) alludes to an approach akin to econometric/input-output models such as those first articulated by Almon et al. (1974) and Buckler, Gilmartin, and Reimhold (1976) and summarized for regional applications by Rey (1998, 2000). He identifies model that enables something he calls “frame shifting,” wherein changes in the levels of final demands as estimated via a standard econometric/I-O model are applied to blocks of a more detailed I-O model. The idea basically seems to be to completely integrate a standard multisectoral forecasting model with I-O accounts (or social accounting matrix [SAMs]) so that estimates for future years of the forecast are assured to be in equilibrium. Concordantly, forecasted portions of some of the series in the econometric/I-O model are used as margins that can be used to update annual I-O accounts into the future. Ideally during the adjustment process by which I-O accounts are updated, substitution across sectors would be subject to Shephard's lemma along the lines develop by Hudson and Jorgenson (1974). What is fascinating is that a model conjoined along these lines would both better regulate time series forecasts so they are in general equilibrium, while annual forecasts of I-O accounts would also be possible. The latter of these attributes has some appeal on three counts. First, such a model could produce a fairly consistent series of capital accounts. Second, one could use such a model to develop I-O accounts and SAMs for future years. And, third, CGE models for a future year could be developed. This last has particular implications for modeling long-run outcomes due to catastrophic events (e.g., enhanced frequency and severity of

storms due to climate change), i.e., conditions under which models based strictly on the historic behavior of economies are likely to fail.

While a full frame-shifting model remains to be realized, work that improves upon econometric/I-O models is still underway. Understanding that somewhere between a third to two-thirds of most nations' gross domestic products by expenditure is in the form of household consumption, Kim, Kratena and Hewings (2015) and Kim, Hewings and Kratena (2015) have been assessing the how much of a difference it makes when household consumption is disaggregated (by income group and age cohort) in the vein of Miyazawa (1976) and Deaton and Muellbauer (1980a, 1980b). The key of this work is that spending differs not just as one ages but also depending upon the generation to which consumers belong. That is, not only have baby boomers changes their purchasing patterns as they have matured, but, at the same age, baby boomers purchased quite differently than millennials do now. Thus, if we can capture both the manner in which a particular age cohort's consumption patterns change over time and also how as different generations pass through a particular age range that range's consumption changes, we should be able to produce better forecasts of economies. This is particularly the case again of attempts at longer run forecasts, in which most series outlooks appear to be fairly linear after the first few future periods.

Disaggregating households is just one tack to take. More can be done. In addition to microdata on households, data exists on spending by various levels of state and local governments that we do not often account for well. The same can be said for technological differences by establishment size or across space.

New Notions of Key Sectors.

After much debate, a series of publications reviewed the realm of proper ways to identify so-called key sectors, as first mentioned by Hirschmann (1958), and the ways to interpret them (Dietzenbacher, van der Linden and Steenge, 1993; Sonis, Hewings and Miyazawa, 1997; Sonis and Hewings, 1999; Miller and Lahr, 2001). Of these, I naturally think Miller and Lahr (2001) is most succinct. A method called "hypothetical extraction" and which can be applied equally to sectors and regions won the day. It essentially measure the difference in an economy before and after removing (or setting to zero) each industry in succession from an I-O table and, subsequently, evaluating which industry would cause the most disruption to the economy. Dietzenbacher and Lahr (2013) go so far as to demonstrate how one can use this same basic approach to measure the impact of extractions of establishment-level information, subsectors, or essentially any intermediate production or demand.

But some issues remain in this line of inquiry. One is the perplexing problem of measuring forward linkages in the wake of Dietzenbacher's (1997), who pointed out that what prior researcher called the supply-side input-out model could not alter quantities. That is perturbations in value added, reflected price changes only, which when limited by Leontief structures showed how in equilibrium those exogenous price changes affect prices across all products supplied and demanded by the economy.

The other main was is that to date key-sector measures have tended to be static concepts (i.e., input-output multipliers). Thus, when included in the conduct of key sector analysis, the growth potential of industries has generally been an entirely separate consideration from those pertaining to interindustry interconnectedness. Moreover, growth potential has almost exclusively been included as future industry magnitudes. Thus, some industries identified as

“key sectors” also had large but steadily decelerating factor (e.g., income, employment) multipliers, which suggests that they may not be worthy of investment from a marginal perspective. Meanwhile other industries with relatively low, but accelerating, factor multipliers were undoubtedly misidentified as unworthy of investment by standard approaches. As I point out elsewhere Lahr (2014), Hirschmann (1958) clearly intended dynamic reflections since he focused on national development issues. With the recent influx of series of international MRIO tables of fairly uniform format and quality, is time to identify growing sectors that enhance economy interconnectedness—key sectors

The aforementioned various series of MRIO tables have spawned some interesting work, of course. Before the international tables were available Oosterhaven and Escobedo-Cardenoso (2011) showed, using a set of Spanish MRIO tables, that regional I-O tables can be reasonably well forecasted. Their innovation was using a lag of the “remainder” from a prior biproportional adjustment technique. More recently, Arto and Dietzenbacher (2014) performed what might be termed a “dynamic” structural decomposition analysis (SDA) to examine the effect of trade changes on the growth of global CO₂ emissions. This immediately harkens parallels to dynamic shift-share analysis (Thirlwall, 1967; Barf and Knight, 1988). Indeed, even the lag of the remainder employed by Oosterhaven and Escobedo-Cardenoso (2011) looks remarkably like the “regional component” (also termed the “competitive effect”) in shift-share analysis (SSA). This is not all that surprising since Rose and Casler (1996) forwarded the idea that the SDA of I-O tableaus were not unlike SSA. (Incidentally, they likened it to growth accounting and index number analysis as well.) Indeed, intuitively SDA demonstrates strong similarities to SSA. Both examine the effects of industry shifts due to growth (or decline) and some sort of difference in industry shares. But SSA works its shares across space while SDA works its shares again across industries via technology change (fabrication effects). Clearly more conceptual work must be done before the two approaches merge. Still, policy work akin to that by Arto and Dietzenbacher (2014) should commence and verification of Oosterhaven and Escobedo-Cardenoso (2011) would be welcome.

Development of Hybrid Tables.

The work that EORA and other data providers has performed shows that unknown data are often not entirely unknown; rather they have ranges and limits and sometimes even known probability distributions (Lenzen et al., 2006, 2009, 2010). As our approaches become more sophisticated, more data sources have become employed. In essence, then, these data additions, become constraints on the uncertainty inherent in unknowns. This means we are inevitably learning more and more about I-O structures as we break out household consumption into income and age groups. It has similar implication to regional accounts when we add in what little aggregate data we might know about trade flows by industry among regions and expenditure patterns by types of government. So while somewhat troublesome to handle, more information is a good thing when applied to input-output tables. *Survey work is worthwhile.* The principle of data enhancement pertains not just to information in input-output tables but also to the data that are used to create them (e.g., labor counts and payroll data). RAS and similar techniques grounded in constrained optimization have tended to be used in such cases, e.g., Golan et al. (1994). As a result, the use and importance of these techniques to our field is quite underestimated. I mention this because very recently Rodrigues (2013, 2014) submitted Bayesian techniques as a solution to help solve the problem. It is therefore clear that ever more-accurate techniques are being applied to estimate missing data that are jointly expressed in spatial and

sectoral hierarchies (e.g., employment data for the nation, state, and municipality and in terms of three-, four-, five-, and six-digit industry classifications). In ways not envisioned early on, I-O can now be produced that incorporate a wide array of data, much of it with very fine spatial and sectoral detail. Indeed, one data provider in the United States—Economic Modeling Specialists International (EMSI)—produces multiregional county-level industry-by-industry input-output tables with 1,000 industries! And such detail this would certainly seem to over-extend information available from the official U.S. 382-industry table produced by the U.S. Bureau of Economic Analysis (BEA), it is likely that economic impacts that emanate from analyses using models with such a fine industrial grain can be no less accurate than those based on BEA-level industry detail or less. This is because EMSI adds detail in those industries that have widely varying wage rates across their sub-industries; they especially focus on industries that tend to be large in economic size, like retail and wholesale trade. The difference in job counts developed in the course of any economic impact analyses using such detail are often substantially different from those expressed by the broader industry average that would ordinarily be the consequence.

Issues with Aggregation.

Indeed, aggregation has always been a major issue where input-output tables are concerned. Early on Leontief (1949, p. 216) noted that “the practical choice is not between aggregation and non-aggregation but rather between a higher and lower degree of aggregation.” A line of research has since led to the conclusion that two sectors should only be aggregated together if they are substitutes or complements and also have the same production functions, with much focus on the latter, however. As may be immediately apparent, these conditions are rarely achieved for firms within an industry, much less across several different sub-industries. EMSI’s perspective is probably best articulated by Balderston and Whitin (1954, p. 79) who note, that “the process of aggregation may obscure important relationships between the components of aggregates. It is even possible that the particular information lost may be more important than the more general information available in the solution made possible by aggregation.” In any case, the data we have at our disposal are rarely as disaggregated as we might prefer, especially for particular research purposes, and this likely will always be the situation. Thus during the past couple of decades an increasing number of empirical studies in our field have examined the effect of aggregation bias on research outcomes. The general outcome has followed expectations—aggregation enhances bias. Exceptions can arise, however, when aggregating already highly aggregated tables (Lahr and Stevens, 2002). These sectoral findings naturally extend to a spatial setting, which is why MRIOs are employed.

Estimating Trade.

This then brings us to the estimation of trade, which like aggregation was not a matter of focus by Hewings and Jensen (1988). Still, it is something that remains an issue at the regional level and was certainly an issue during the recent spate of international MRIO developments (see, Osterhaven, Stelder, and Inomata, 2008). While the problem at the international level is conflicting data from exporting and importing countries—in a manner of speaking, an overabundance of data, the main issue at the subnational level is a lack of viable data. The need for intra-national, interregional trade data is most pronounced in spatially large countries (Russia, China, Canada, the United States, Brazil, Australia, and India) where price distortions induced by transportation costs are prevalent. An added issue is how to deal with international trade at the regional level: in the absence of data to the contrary, international imports at least are distributed in a spatially constant manner during the construction of regional economic models, albeit also

depending on the level of production of each import-using industry. Basic approaches as described by Batten and Martellado (1985) still tend to be applied. Still, efforts by Canning and Wang (2005), Southworth (2005), Jackson and Schwarm, (2011), Southworth et al. (2011), and Valma (2014) among others show that more data and better algorithms are being applied. Indeed, due to the lack of survey data across all commodities and regions by freight mode, a key issue is identifying the proper geography for measuring interregional trade and developing models with the sparse data available that will enable the development of a database with sufficient geographic and industry detail, by mode, assuming one can estimate regional supply and demand levels.

Recall that Fox and Kumar (1965) suggested that, for reasons related to hierarchies of urban areas, functional economic areas should be used for measuring trade rather than political areas like states. But audiences of policy modeling work require political regions. This means we should be estimating trade patterns derived via functional economic areas (and often splitting them) to produce decent policy models in multiregional fashion for political geographies. We are not doing this yet.

Conclusions

It should be evident from the above that opportunities abound for young interindustry analysts. I have reviewed just a handful or two of general topics here because they are inherently regional in nature. While the challenges are great, the field of input-output analysis has been quite revitalized through enhanced global interest in a more sustainable and just world. Thankfully more and better tools and data are available to us now than ever before to tackle some of the issues that stand before us. For example, notions like value chains (Timmer et al. 2014; Los, Timmer, and Vries, 2015) and lifecycle assessment (Hendrickson, Lave, and Matthews, 2006), average propagation lengths (Dietzenbacher and Romero, 2007) and dynamic decomposition (Kuroda and Kimura, 2004) have been used little, if at all, at the regional level—and there are many other tools like this in our arsenals.

Keep in mind that topics in health, climate change, the environment, and energy presently get high citation ratings. This means that working in such areas can be quite rewarding when it comes to publication value. But if you do, it can also mean that ten other research teams could publish on your ideal topic before you do, as others may be equally informed about what topics are hot.

Impact analyses, static key-sector analyses, cluster analysis, supply-side modeling, and examinations of the bias of multipliers in a stochastic setting are topics and approaches that are unlikely to be very fruitful, at least insofar as journal publications are concerned. Of course, I will readily acknowledge that, in the form of policy work and funded studies, impact, key-sector, and cluster analyses can help sustain a family of four. Of course, closure of some topics opens the door for others. For example, if the Leontief price model (previously termed the “supply-side” or “Ghosh” model) does not measure forward linkages properly, what does? If static key-sector and industry cluster techniques are not worthwhile to pursue (see Jackson, 2015), what techniques might be useful instead? With the various sets of international MRIO tables available, we should be able to test the value of any pertinent measures. In fact, how can we use the recent proliferation of international MRIO databases to advance subnational input-output analysis more generally?

A main thing is to remember that no one expects you to develop a general theory or grand synthesis in the course of your career. But that does not mean you should not keep one in mind. Indeed, perhaps we need to think outside of the box (or should I say matrix) in order to break out of our self-imposed methodological limits and public policy aspirations. I started off with I-O tales from when the world seemed limited only my calculation capabilities...to show how our field changed when the yoke was thrown off. Now that we have world models, we need to think even bigger!

REFERENCES

- Acemoglu, Daron, Vasco M. Carvalho, Asuman Ozdaglar and Alireza Tahbaz-Salehi. (2012) "The Network Origins of Aggregate Fluctuations," *Econometrica*, 80, 1977–2016.
- Almon, Clopper, Margaret B. Buckler, Lawrence C. Horowitz, and Thomas C. Reimbold. (1974) *1985: Interindustry Forecasts of the American Economy*. Lexington Books: Lexington, MA.
- Arto, Iñaki and Erik Dietzenbacher. (2014) "Drivers of the Growth in Global Greenhouse Gas Emissions," *Environmental Science and Technology*, 48, 5388–5394.
- Balderston, J. B. and T. M. Whittin. (1954) "Aggregation in the Input Output Model," in Oskar Morgenstern (ed.), *Economic Activity Analysis*. New York: John Wiley and Sons Inc.
- Barff, Richard A. and Prentice L Knight III. (1988) "Dynamic Shift-Share Analysis," *Growth and Change*, 19(2), 1–10.
- Batten, David and Dino Martellato. (1985) "Classical versus Modern Approaches to Interregional Input-Output Analysis," *Annals of Regional Science*, 19(3), 1–15.
- Beaumont, Paul M. (1990) "Supply and Demand Interaction in Integrated Econometric and Input-Output Models," *International Regional Science Review*, 13, 167–181,
- Berger, W. J. and Edward Saibel (1957) "Power Series Inversion of the Leontief Matrix," *Econometrica*, 25, 154–165.
- Buckler, Margaret B., David Gilmartin, and Thomas C. Reimhold. (1976) "The INFORUM Model," in Karen R. Polenske and Jiri Skolka (eds.) *Advances in Input-Output Analysis*. Ballinger Publishing Company: Cambridge, MA, pp. 297–327.
- Canning, Patrick, and Zhi Wang. (2005) "A Flexible Mathematical Programming Model to Estimate Interregional Input–Output Accounts," *Journal of Regional Science*, 45, 539–563.
- Deaton, Angus and John Muellbauer. (1980a) "An Almost Ideal Demand System," *American Economic Review*, 70, 312–326.
- _____. (1980b) *Economics and Consumer Behavior*. Cambridge University Press: New York
- Dietzenbacher, Erik. (1997) "In Vindication of the Ghosh Model: Reinterpretation of a Price Model," *Journal of Regional Science*, 37, 629–651.
- Dietzenbacher, Erik and Michael L. Lahr. (2013) "Expanding Extractions," *Economic Systems Research*, 2, 341–360.

- Dietzenbacher, Erik, Jan A. van der Linden, and Albert E. Steenge. (1993) "The Regional Extraction Method: EC Input-Output Comparisons," *Economic Systems Research*, 5, 185-206.
- Dietzenbacher, Erik and Isidoro Romero. (2007) "Production Chains in an Interregional Framework: Identification by Means of Average Propagation Lengths," *International Regional Science Review*, 30, 362–383.
- Dwyer, Paul S. and Frederick V. Waugh. (1953) "On Errors in Matrix Inversion," *Journal of the American Statistical Association*, 48, 289–319.
- Evans, W. Duane. (1954) "The Effect of Structural Matrix Errors on Interindustry Relations Estimates," *Econometrica*, 22, 461–480.
- _____. (1956) "Input-Output Computations," in Tibor Barna (ed.), *Structural Interdependence of the Economy*. John Wiley: New York, pp. 51–102.
- Fox, Karl A. and T. Krishna Kumar (1965) "The Functional Economic Area: Delineation and Implications for Economic Analysis and Policy," *Papers in Regional Science*, 15, 57–85.
- Golan, Amos, George Judge, and Sherman Robinson, (1994) "Recovering Information from Incomplete or Partial Multisectoral Economic Data," *Review of Economics and Statistics*, 76, 541–549.
- Hendrickon, Chris T., Lester B. Lave, and H. Scott Matthews. (2006) *Environmental Life Cycle Assessment of Goods and Services: An Input-output Approach*. Resources for the Future Press: Washington, D.C.
- Hewings, Geoffrey J. D. and Rodney C. Jensen. (1988) "Emerging Challenges in Regional Input-Output Analysis," *Annals of Regional Science*, 22, 43–53.
- Hirschman, Alfred O. (1958) *The Strategy of Economic Development*. Yale University Press: New Haven. CT.
- Holley, Julian L. (1954) "Note on the Inversion of the Leontief Matrix," *Econometrica*, 79, 317–320.
- Hotelling, Harold.(1945) "Practical Problems of Matrix Calculation," In *Proceedings of the Berkeley Symposium on Mathematical Statistics and Probability*, pp. 275–293, available online in November 2015 at <https://projecteuclid.org/euclid.bsm/1166219209>.
- Hudson, Edward A. and Dale W. Jorgenson. (1974) "U.S. Energy Policy and Economic Growth," 1975-2000," *Bell Journal of Economics*, 5, 461–514.
- Hull, Clark L. (1925) "An Automatic Correlation Calculating Machine," *Journal of the American Statistical Association*, 20, 522–531.
- Israelevich, Philip. (2002) "Frame-Shifting in Regional General Equilibrium Models," in Geoffrey J.D. Hewings, Michael Sonis, and David Boyce (eds.), *Trade Networks and Hierarchies: Modeling Regional and Interregional Economies*. Springer-Verlag: New York, pp. 387–405.
- Jackson, Randall W. (2015) "Are Industry Clusters and Diversity Strange Bedfellows?," *Review of Regional Studies*, 45, 113–129.

- Jackson, Randall W. and Walter R. Schwarm. (2011) "Accounting Foundations for Interregional Commodity-by-Industry Input-Output Models," *Letters in Spatial and Resource Sciences*, 4, 187–196.
- Kim, Kijin, Geoffrey J. D. Hewings, and Kurt Kratena. (2015) "Household Disaggregation and Forecasting in a Regional Econometric Input–Output Model," *Letters in Spatial and Resource Sciences*, <http://link.springer.com/article/10.1007%2Fs12076-015-0140-8>.
- Kim, Kijin, Kurt Kratena, and Geoffrey J. D. Hewings. (2015) "The Extended Econometric Input–Output Model with Heterogeneous Household Demand System," *Economic Systems Research*, 27, 257–285.
- Kremer, Michael. (1993) "The O-Ring Theory of Economic Development," *Quarterly Journal of Economics*, 108, 551–575.
- Kuroda, Masahiro and Koji Numura. (2004) "Technological Change and Accumulated Capital: A Dynamic Decomposition of Japan's Growth," in Erik Dietzenbacher and Michael L. Lahr (eds.), *Wassily Leontief and Input-Output Economics*. Cambridge University Press: New York, pp. 256–293.
- Lahr, Michael L. (2014) "Square Dancing with the Stars to Enhance Dynamic Hirschman Linkages?," *Review of Regional Studies*, 44, 111–123.
- Lahr, Michael L. and Benjamin H. Stevens. (2002) "A Study of the Role of Regionalization in the Generation of Error in Regional Input-Output Models," *Journal of Regional Science*, 42, 477–507.
- Lenzen, Manfred, Blanca Gallego, and Richard Wood. (2006) "A Flexible Approach to matrix Balancing under Partial Information," *Journal of Applied Input-Output Analysis*, 11/12, 1–24.
- _____. (2009) "Matrix Balancing under Conflicting Information," *Economic Systems Research*, 21, 23–44
- Lenzen, Manfred, Richard Wood, and Thomas Wiedmann. (2010) "Uncertainty Analysis for Multi-Region Input-Output Models—A Case Study of the U.K.'s Carbon Footprint," *Economic Systems Research*, 22, 43–63.
- Lenzen, Manfred, Daniel Moran, Keiichiro Kanemoto, and Arne Geschke. (2013) "Building Eora: A Global Multi-regional Input-Output Database at High Country and Sector Resolution," *Economic Systems Research*, 25, 20–49.
- Leontief, Wassily W. (1941) *The Structure of American Economy, 1919-1929: An Empirical Application of Equilibrium Analysis*. Harvard University Press: Cambridge, MA.
- _____. (1949) "Recent Developments in the Study of Interindustrial Relationships," *Papers and Proceedings of the American Economic Association*, 211–225.
- Los, Bart, Marcel P. Timmer, and Gaaitzen J. Vries (2015) "How Global Are Global Value Chains? A New Approach to Measure International Fragmentation," *Journal of Regional Science*, 55, 66–92.
- Lucas, Robert (1976) "Econometric Policy Evaluation: A Critique," in Karl Brunner and Allan H. Meltzer (eds), *The Phillips Curve and Labor Markets*. New York: Elsevier, pp. 19–46.

- Maaß, Siegfried. (1980) *Die Reagibilität von Prognosen mittels Input-Output-Modellen auf Fehler im Datenmaterial: Gezeigt am Beispiel des statischen offenen Leontief-Modells.* Heft 297. Berlin: Dunker & Humblot
- Miyazawa, Ken'ichi. (1976) *Interindustry Analysis and the Structure of Income Distribution.* Springer-Verlag: Berlin.
- Neisser, Hans P. (1941) "A Review of Wassily W. Leontief's The Structure of American Economy, 1919-1929: An Empirical Application of Equilibrium Analysis.," *American Economic Review*, 31, 608–610.
- Nurske, Ragnar. (1952), "Growth in Underdeveloped Countries," *American Economic Review*, 42, 571–583.
- Oosterhaven, Jan and Fernando Escobedo-Cardenoso. (2011) "A New Method to Estimate Input-Output Tables by Means of Structural Lags, Tested on Spanish Regions," *Papers in Regional Science*, 90, 829–844.
- Oosterhaven, Jan, Dirk Stelder and Inomata. (2008) "Estimating International Interindustry Linkages: Non-survey Simulations of the Asian-Pacific Economy," *Economic Systems Research*, 20, 395–414.
- Rey, Sergio J. (1998) "The Performance of Alternative Integration Strategies for Combining Regional Econometric and Input-Output Models," *International Regional Science Review*, 21, 1–36.
- _____. (2000) "Integrated Regional Econometric+Input-Output Modeling: Issues and Opportunities," *Papers in Regional Science*, 79, 271–292.
- Robison. M. Henry and Kelly Gneiting. (1999) *A Multiregional Input-Output Model for Estimating Economic Impacts in TELUS: Role Data Sources and technical Specifications.* Economic Modeling Specialist Inc.: Moscow, ID.
- Rodrigues, João F. D. (2013) "The Prior Uncertainty and Correlation of Input–Output Data," Paper presented at the 21st International Input–Output Conference, Kitakyushu.
- _____. (2014) "A Bayesian Approach to the Balancing of Statistical Economic Data," *Entropy*, 16, 1243–1271.
- Rose, Adam Z. and Stephen D. Casler. (1996) "Input–Output Structural Decomposition Analysis: A Critical Appraisal," *Economic Systems Research*, 8, 33–62.
- Rose, Adam Z., Kenneth hanson, and Ping-Cheng Li. (2001) "Income Distribution Effects of Government Transfers: Sensitivity to Closure Rules in Input-Output and Computable General Equilibrium Approaches," in Michael L. Lahr and Erik Dietzenbacher (eds.), *Input-Output Analysis: Frontiers and Extensions*, Palgrave: new York, pp. 479–501.
- Rosenstein-Rodan, Paul N. (1943) "Problems of Industrialization of Eastern and South-Eastern Europe," *Economic Journal*, 53, 202–211.
- Scarf, Herbert. (1969) "An Example of an Algorithm for Calculating General Equilibrium Prices," *American Economic Review*, 59, 669–677.
- Schumpeter, Joseph A. (1942) *Capitalism, Socialism and Democracy.* London: Routledge.

- Scitovsky, Tibor. (1954) "Two Concepts of External Economies," *Journal of Political Economy*, 62, 143-151.
- Sherman, Jack and Winifred J. Morrison. (1949) "Adjustment of an Inverse Matrix Corresponding to Changes in the Elements of a Given Column or a Given Row of the Original Matrix (Abstract)," *Annals of Mathematical Statistics*, 20, 621.
- _____. (1950) "Adjustment of an Inverse Matrix Corresponding to a Change in One Element of a Given Matrix," *Annals of Mathematical Statistics*, 21, 124-127.
- Shoven, John B. and John Whalley. (1972) "A General Equilibrium Calculation of the Effects of Differential Taxation of Income from Capital in the U.S.," *Journal of Public Economics*, 281-321.
- Sonis, Michael and Geoffrey J. D. Hewings. (1999) "Miyazawa's Contributions to Understanding Economic Structure: Interpretation, Evaluation and Extensions," in Geoffrey J. D. Hewings, Michael Sonis, Moss Madden and Yoshio Kimura (eds.), *Understanding and Interpreting Economic Structure*. Berlin and Heidelberg: Springer-Verlag, pp. 13-51.
- Sonis, Michael, Geoffrey J.D. Hewings, and Ken'ichi Miyazawa. (1997) "Synergetic Interactions within the Pair-wise Hierarchy of Economic Sub-systems," *Hitotsubashi Journal of Economics*, 38, 183-199.
- Southworth, Frank. (2006) "Filling Gaps in the U.S. Commodity Flow Picture Using the CFS with Other Data Sources," in Kathleen Hancock (ed.), *Commodity Flow Survey Conference, Transportation Research Circular, Number E-C088*, Transportation Research Board: Washington, DC, pp. 29-46.
- Southworth, Frank, Bruce E Peterson, Ho-Ling Hwang, Shih-Miao Chin, and Diane Davidson. (2011) "A Description of the FAF3 Regional Database and How It Is Constructed," a report to the Federal Highway Administration. Oak Ridge National Laboratory: Oak Ridge, TN. <http://faf.ornl.gov/fafweb/Data/FAF3ODDoc611.pdf>.
- Stevens, Benjamin H. (1990) "A Note on the Usefulness of the 'Round-by-Round' Method of Performing Input-Output Impact Calculations," In Manas Chatterji and Robert E. Keunne (eds), *Dynamics and Conflict in Regional Structural Change: Volume 2, Essays in Honour of Walter Isard*. Macmillan Press: London, pp. 279-289.
- Thirlwall, Anthony P. (1967) "A Measure of the 'Proper Distribution of Industry'" *Oxford Economic Papers*, 19, 46-58.
- Marcel P. Timmer, Abdul Azeez Erumban, Bart Los, Robert Stehrer and Gaaitzen J. de Vries. (2014) "Slicing Up Global Value Chains," *Journal of Economic Perspectives*, 28(2), 99-118.
- Tukker, Arnold and Erik Dietzenbacher (2013) "Global Multiregional Input-Output Frameworks: An Introduction and Outlook," *Economic Systems Research*, 25, 1-19
- Valma, Erasmia. (2014) "Estimation of Interregional Trade Coefficients and Multipliers in the Context of an Interregional Model," *European Research Studies*, 17, 101-118.
- Walras, Léon. (1898) *Études d'économie politique appliquée:(Théorie de la production de la richesse sociale)*. Lausanne: Librairie de l'Université.

- Waugh, Frederick V. (1950) "Inversion of the Leontief Matrix by Power Series," *Econometrica*, 18, 142–154
- Waugh, Frederick V. and Paul S. Dwyer. (1945) "Compact Computation of the Inverse of a Matrix," *Annals of Mathematical Statistics*, 16, 259–271.
- Woodbury, Max A. (1950) "Inverting Modified Matrices," *Memorandum Report No. 42*. Statistical Research Group, Princeton University, Princeton, NJ.