CHANNELS OF SYNTHESIS FORTY YEARS ON: INTEGRATED ANALYSIS OF SPATIAL ECONOMIC SYSTEMS

by

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Abstract

Isard's vision of integrated modeling that was laid out in the 1960s book *Methods of Regional Science* provided a road map for the development of more sophisticated analysis of spatial economic systems. Some forty years later, we look back at this vision and trace developments in a sample of three areas – demographic-econometric integrated modeling, spatial interaction modeling, and environmental-economic modeling. Attention will be focused on methodological advances and their motivation by new developments in theory as well as innovations in the applications of these models to address new policy challenges. Underlying the discussion will be an evaluation of the way in which spatial issues have been addressed, ranging from concerns with regionalization to issues of spillovers and spatial correlation.

Keywords: Spatial economic system, Integrated analysis,
JEL Classification: O18, O21, R10, R11

Introduction

Forty years ago, spatial analysis had quite a different connotation in the conduct of research; terms such as systems analysis, integrated modeling and calibration were not part of the lexicon of all but a few papers published in the geographical literature. In the intervening years, there has been a steady appreciation of systems thinking in the conduct of spatial analysis but for the most part, modeling has remained modest in scope in the sense that large-scale, integrated systems have not been a prominent feature. In this paper, an attempt will be made to review the impact of some initial proposals presented in Isard (1960) to forge greater integration across models in the hope of uncovering important insights into how the system of regional economies within a country functioned, grew and developed.

Isard's (1960) vision, contained in a chapter entitled "Channels of Synthesis," provided several alternative ways in which some (now) standard models of parts of the economy (demographic, economic, spatial interaction) could be integrated. Integration was not desired merely to introduce greater complexity; there was a fundamental belief that (1) there was insufficient endogeneity in most models and (2) some of the important challenges lay at the interface between models. For example, the standard economic base model assumes a multiplier process that generates the mechanism underlying growth in a regional economy; however, this growth is likely to enhance the attractiveness of the region and thus potentially increase in-migration. Additional in-migrants in turn, would generate demand for housing, consumer goods and a variety of public services. In some cases, these demographically induced effects may be as significant as the indirect economic impacts generated by the original stimulus to the economy (assumed to be the result of an increase in exports). For many decades, economic base modelers and demographers toiled in parallel fashion; Czamanski (1964) and Ledent (1978) among others developed ways of integrating the two models that clearly demonstrated the need to pay attention to the synergetic linkages between demographic and economic processes. In so doing they also demonstrated the attractiveness of making more interactions endogenous, thereby enhancing the value of the model and its ability to provide insights into the operation of regional economies.

In this paper, the original stimulation for this development, Isard (1960) will be reviewed briefly and three areas will be sampled in turn to provide some perspectives of current state of the art in integrated modeling, namely, economic-demographic models, spatial interaction models and finally economic-environmental models. The paper concludes with some summary evaluation.

Channels of Synthesis

In its fifty years of existence, the field of regional science has witnessed cycles of model building that parallel the behavior of economies; while the field is still too young to have witnessed a long-run Kondratieff type of cycle, there have been pronounced shifts in the way the models have been constructed, their spatial scale and the degree to which the models attempt to replicate general equilibrium features even if their spirit is more general rather than equilibrium-oriented. A discussion of many of these trends can be found in Batey and Madden (1986), Harrigan and McGregor (1988), Anselin and Madden (1990); furthermore, Boyce (1988) provided a call for a new look at large-scale modeling in his presidential address to the Regional Science Association.

Recall that Isard (1960) presented a series of methods to address a variety of dimensions of the regional economy – economic, demographic, interactive and so forth. In one extensive chapter, "Channels of Synthesis," the drive towards synthesis and integration was begun. The goal here was to begin the process of integration in a way, to put it very simply; the exogenous components of one model would be endogenized through integration with one or more other models. For example, the initial channel proposed an interregional comparative cost-industrial complex input-output framework; another explored structures within urban-metropolitan regions, another with articulation of appropriate goals and exploration of new applications of gravity models. Isard (1960) was clearly pointing out some possibilities and much of the discussion was conceptual in nature; data were not available on the one hand but, more importantly, comparatively little effort had been directed to the way in which these models might be linked. As a result, the arrows linking models were suggestive of potential relationships rather than based on sound, theoretical arguments about the way in which a location-allocation system and a set of interregional input-output accounts could be linked as one example (see figure 1).

<<insert figure 1 here Isard p. 571>>

It was to be twenty years before this issue, of model integration, was revisited. At the time of the 1980 First World Congress of the Regional Science Association in Cambridge, MA, a group of scholars met to explore some ways in which the ideas outlined in 1960 might be reworked into an operational system. A summary of these developments may be found in Isard and Anselin (1982). Several points should be made here; first, there was an obvious deepening of understanding of the structure of the individual models. Without exception, they were now more complex and sophisticated, with greater attention to handling nonlinearities together with new developments in computer simulation and algorithm development. However, the "wiring diagram" (too large to be reproduced here) still suggests that the comparative balance between intra-model development and inter-operability between models was still heavily biased towards the former. This was acknowledged and formed the basis for an application for funding to the US National Science Foundation; the argument advanced was that the potential for significant developments in understanding the structure and functioning of the spatial economy would come from having a group of scholars focus on the ways in which their models could be integrated. Unfortunately, the magnitude of the funding request ($6 million) quite overwhelmed most reviewers who saw the opportunity cost in terms of a significantly shrunken funds for the rest of the field as too great; the proposal was denied funding. In addition, there was no doubt, that fears of black-box model development preoccupied many reviewers. In this sense, incrementalism (working on extensions to smaller models) was to be preferred over what might have been considered a great leap forward.

In retrospect, for reasons that will be advanced later in this paper, this was a missed opportunity. Social scientists seem to be uncomfortable with the great Chicago architect Daniel Burnham's dictum "make no small plans…." While colleagues in other disciplines organize their activities on much larger scales, social science in general still seems to operate on a predominantly single-scholar mode. Time and time again, problems have arisen as a result of our lack of understanding (or misunderstanding) of the way one part of the economy affects the other; "ceteris paribus" has been a comfortable mantra to adopt since it simplifies the analysis often at the cost of ignoring some of the greatest challenges.

The 1960 set of visions provided by Isard were strongly rooted in the way a set of modules could be linked. Even in this early venture, considerable weight was placed on the articulation of a set of goals for the system to be modeled. Apart from the more familiar economic goals, Isard included social and political concerns; these were viewed as outcomes of values that were strongly based on the prevailing cultures of the economy being modeled. These goals were then to be linked to a set of social accounts and to an interregional linear programming system in one version; alternative versions included a variety of spatial scales to be addressed via probability, gravity and potential models. In this chapter, there were enough potential doctoral dissertations to provide challenges for several generations of students. Even so, Isard (1960) did note:

"We cannot claim that we have presented an exhaustive list of research projects; we hope, however, to have noted the more important ones. Nor can we claim that we have exhaustively spelled out the various techniques for regional analysis and developed their potential in full. For the vast field of regional science….must probe the area of theory – theory which has regional and interregional structure and function at its core."

Forty years later, the challenge remains largely unmet; enormous strides have been made but the field of regional science continues to be dominated by research that is still narrowly focused. In the final section of this paper, attention will be directed once more to these challenges and to Isard's more recent presentation of the new channels of synthesis (Isard et al 1998). In the next three sections, some review and evaluation will be made of three areas in which there has been some significant movement towards integration – demographic-econometric integrated modeling, spatial interaction modeling and environmental-economic modeling.

Demographic-Econometric Integrated Modeling

In many of Isard's (1960) proposals, an integration of social accounts (broadly defined) with linear programming models formed a prominent role; the Isard and Anselin (1982) proposal offered opportunities for links between input-output and a variety of econometric specifications, with, for example, a factor demand/investment supply module interfacing with an input-output programming module on the one hand while a national module provided the "upper level" signals for the regional system. Over the last three decades, there have been many different versions of models that have integrated input-output and econometric formulations, some of which were embedded in an even more comprehensive general equilibrium framework. Rey (1997, 1998, 2000), Rey and Dev (1997), West (2002) and West and Jackson (1998) have all covered many of the features of these models in some detail. To use Boyce's (1988) distinction, some of these models are de facto single models while others are a series of linked submodels. Hence, it is important to make a distinction between integration and linkage; it would not be unfair to characterize many of the propositions in Isard (1960) as examples of the latter; Boyce (1988) suggested that integration, on the other hand, would involve a unifying mathematical formulation and its realization in appropriate algorithms and computer code. In another sense, the process might be referred to as one of embedding since it is often possible to extract the submodels under certain circumstances (see Israilevich *et al*., 1996 for an example).

As noted earlier, while Czamanski (1964) provided some initial step in the integration of demographic and economic models in extending the economic base model to include demographic components and the explicit feedback between population and employment growth, the series of integrated models prepared by Batey and Madden (1983) for the Merseyside region of England initiated a renewed integration trend by drawing attention to the significant insights to be gained from integrating demographic and economic systems (a more comprehensive review of their work can be found in Anselin and Madden (1990), Hewings and Madden (1994), see also Batey (1985) for a valuable typology of model structures). Theoretical and empirical analyses had long drawn attention to the role of consumption behavior at the regional level; however, by adopting an activity-analysis framework, Batey and Madden (1983) disaggregated consumption into households of two groups – employed and unemployed workers. Further, the movement from one group to another involved either an incremental or marginal consumption impact in response to an increase or decrease in income associated with accepting a job or loosing one. The initial system is shown in figure 2; note that this is a true integrated model whose solution could be obtained through either iteration or through matrix manipulation.

<<insert figure 2 here Batey-Madden>>

Batey and Madden (1999) were able to show how their formulation shares much in common with the earlier extensions of simple input-output accounts proposed by Miyazawa (1976). Miyazawa's work, in turn, can be considered as an intermediate step towards the development of full social accounting systems (see the excellent evaluation of these developments by Pyatt, 2003). However, while the models of Batey and Madden share some of the characteristics of social accounting systems, they provide a more extensive modeling of the labor market than most traditional social accounting systems. Perhaps, one of their more important contributions has been to provide an opportunity to consider both average and marginal consumption impacts within the same model and thus to provide a better tie to consumer behavior. In Batey and Madden (1999), a more extensive range of demographic input variables was proposed including migration, changes in commuting, natural changes in the size of the labor force, economic activity rate changes in the labor force, and changes in the retired and inactive population (see also Batey and Weeks, 1987, 1989 and Van Dijk and Oosterhaven 1986 for formal links with unemployment and migration behavior).

Batey and Madden's work may be seen as an initial step on a journey towards more general equilibrium approaches to regional modeling; while missing many aspects of current computable general equilibrium models, the focus on the labor market, migration and other demographic attributes sets it apart from almost all other integrated models. However, it is in the area of computable general equilibrium models that some of the more important developments have taken place. Most of the models may be regarded as Walrasian in form in that prices adjust to clear markets and differ in terms of detail about product markets, the handling of externalities, closure rules and the specification of production behavior (especially production functions and the nature of the market conditions – see Partridge and Rickman, 1998). The modeling system of this form that embodies Isard's (1960) admonition to draw on theory for model development is the AMOS system developed by colleagues at the Fraser of Allander Institute at Startclyde University in Scotland (Harrigan *et al*., 1988, 1991; McGregor *et al*., 1995, 1996, 1999; Gillespie *et al*., 2002). One of the many distinguishing features of this modeling system is the strong tie between the model and received economic theory; a conscious attempt has been made to make the system tractable. This is even more important in view of the variety of policy-related applications that have been conducted with the model. Of particular note is the role of wage-bargaining wherein a price-taking region (Scotland) and the price-setting Rest of the UK can be modeled under varying conditions of labor mobility. The result is a system in which the analyst can move from theory to formulation to empirical implication and policy evaluation with total transparency; further, by limiting the size of the system more of the functional forms can be estimated econometrically without reliance on extensive borrowing. In many computable general equilibrium models, it has become common practice to use estimates from other models in combination with local data. With many of these models now numbering hundreds (and many times thousands) of equations, this is inevitable. However, it does raise concerns about the sensitivity of the models to parameter estimation and the degree to which their "cookie-cutter" production reduces their ability to reflect idiosyncrasies about the economies they aim to model.

This review has focused on analysis conducted at the regional or interregional scale; there is an extensive, parallel literature that has explored integration of models within metropolitan systems, building on and extending the Lowry-Garin model to handle more sophisticated journey-to-work models. The issues here address ways in which area based models of economies can be linked with network systems (see Lundqvist *et al*., 1998). In the next section, the role of spatial interaction between regions will be considered.

Spatial Interaction Modeling

Isard's view about the importance of spatial interaction is best depicted in p. 183 of his 1960 volume:

'A far-sighted resources development analyst, although he may be concerned with a particular region, investigates further. Regions are not isolated entities. They are interrelated. *To any given region are transmitted the ups and downs of regions which are its neighbors*' (italics added).

As implied by the definition of region, i.e., a spatial sub-unit of a country, interregional interaction is not only inevitable, it is often the key to enhancing the success of a region. On a broader sense, Fotheringham and O'Kelly (1989) argue that spatial interaction has a unique position in economic development, a process that facilitates the exploitation of efficiency offered by various regional or spatial specializations. The latter requires smooth spatial interaction that facilitates the exchange of goods and services among spatial units. In addition, if the integrated systems described in the earlier section are to be extended to multiregional (or multi-economy contexts), then the way in which these linkages are specified becomes critical. In this regard, it is interesting to note the recent acknowledgment of the importance of spatial interaction in the international trade literature where, for so long, trade was modeled without reference to any geographic properties of the countries involved (see Bergstrand, 1985, Frenkel, 1999)

The notion of spatial interaction appears in three themes in Isard's (1960) regional analysis: the interregional input-output, interregional linear programming, and the probability or potential or gravity model. The importance of each of these themes is stressed further in its pivotal position in facilitating the channels of synthesis. Serving as alternative paths for understanding regional economic systems, these channels have a unifying, clear message: in a system comprising some sub-national entities, where interaction is inevitable, attention must be given to the existence of interregional spillover effects, since performance of a specific region may be affected by development in the neighboring regions.

Nowadays the term 'spatial interaction model' is closely associated with the potential, gravity or entropy maximizing models. The formulations assume that interaction between two localities is positively related to the mass of the localities and negatively related to their distance, referred to as the first law of geography (Tobler 1979): all locations on the map are related, but closer locations are more so than distant ones. The gravity model has been applied to migration analysis (e.g., Tobler 1979, Plane and Regerson 1994), market size analysis (e.g., Haynes and Fotheringham 1984), location-allocation problem, and network analysis (e.g., Fotheringham and O'Kelly 1989), interregional trade analysis (e.g., Fischer and Johansson 1996; Schneider and Fischer 2001). More extensive theoretical and empirical issues are addressed in Fotheringham and O'Kelly (1989), Sen and Smith (1995) and Roy (2003).

One major criticism directed to the potential and gravity model is that it lacks a microeconomic basis, and this may explain why such model did not make its way to the economics literature (Krugman 1996, but see also Bergstrand 1985). While the model predicts a certain way of behavior among localities, it is not clear who are the agents and what motivates their behavior. This criticism is related to another problem that the potential and gravity model is basically an aggregate model, i.e., inconsistent with individual behavior. In the response to these critiques, Roy (2003) has noted where economic relationships are acknowledged in the behavioral part of spatial interaction model. In fact, Roy (2003) has provided one of the most important integrative perspectives, placing spatial interaction modeling firmly into the forefront of a great sweep of demographic-economic modeling; his approach provides a holistic assessment of the gravity, potential, entropy maximizing and most probable state models but, more importantly, provides some key insights into ways in which these formulations can be used to integrate models involving multiple economies.

However, spatial interaction models are not only limited to the gravity model. In a rigorous exposition Dendrinos and Sonis (1990) provide extensive mathematical discussion of more general socio-spatial dynamics of stocks. They point out that spatial interaction can be characterized by chaotic, complex or unpredictable behavior; even with the implied homogeneity assumption is upheld. The application of this model for economic variables can be seen, for example, in Hewings *et al* (1996) while an extension of the method to incorporate hierarchical structure of regional interaction can be found in Nazara *et al* (2001). This modeling framework departs from the standard gravity ideas to basically posit a competition between regions for a share of some national aggregate. As such, the model involves consideration of relative dynamics; however, the "space" over which competition is posited is not specified formally.

Competing models have been major characteristics of scientific explorations. That is also true in the spatial interaction modeling literature. A general agreement among scholars is that any proposed models are basically an approximation of the underlying unknown reality. Inside every single model is a set of assumption on the relationship among relevant variables; for some researchers, this is too restricted an approximation. Recent developments in spatial interaction models start to adopt an unconstrained model, known in the literature as the neural network, where there is no requirement to assume an a priori model. Its application to the spatial interaction model gives way to what has become the network spatial interaction model. Examples of research in this subject include, among others, Fischer and Gopal (1994); Black (1995); Fischer et al (1999); Reggiani and Tritapepe (2000); Thill and Mozolin (2000); Mozolin, Thill and Usery (2000). Kim *et al*., (2002) Kim and Hewings (2003) have explored ways in which spatial interaction on a network can be integrated with multiregional macroeconomic models, presenting opportunities to exploit new developments in network economics to consider the ways in which multiple link improvements or construction generate a system-wide impact (see also Nagurney, 2000).

Attention to the role of spatial interaction is not limited to identifying them, but also how they affect various data generating processes in the economy. It is worth noting here the development of spatial econometrics (Anselin 1988, Anselin and Florax 1995), a branch of econometric theory that gives important attention to the spatial structure in the data. The main postulate to hold here is that the true data generating process does not take place in the world where spatial units are independently and identically distributed. In fact, given a definition that a region is a sub-national unit, regions are interrelated, the extent of which needs to be taken into account in the regression-type inferences. Typically, the a priori spatial interaction is depicted in a weight matrix representing the degree of interaction between two different spatial units in the analysis.

To what kinds of spatial structure are these economic variables responsive? The standard practice in spatial econometrics typically employs the notion of neighborhoodness; a way to define one is the use of the common border criterion, i.e., simple contiguity. However, such an iso-intensive interaction structure is challenged by the importance of physical distances in interaction. As is asserted by the gravity theory, as well as the first law of geography (Tobler 1979), interaction between two different spatial units is a decreasing function of their distances. This very last point stimulates competing perspective about the importance of economic, in contrast to physical, neighborhoodness in explaining the true process. There is a growing body of literature exploiting various economic variables, such as interregional trade or interregional migration, as the presumed underlying spatial interaction in the data generating process. Of course, such an approach comes with a price: the use of economic variables to depict interregional interaction in a weight matrix can cause multicolinearity with other economic variables that may constitute the explanation of the problem at hand.

While spatial structure is typically considered as taking place among spatial units, a challenging area in this matter is to view this structure with some additional dimensions. In regional analysis, these dimensions may consist of several types. First is the economic sector: economic sectors in each region may be in unique interaction one with another. At this point, use could be made of an interregional input-output model to explore and model these interactions. Secondly, temporal interaction: different structures may be foreseeable over time. The combination of spatial interaction with these two dimensions will be a challenging area for future analysis as extensive spatio-sectoral-temporal models are developed. Thirdly is the hierarchical structure; in regional analysis, the importance of hierarchy is warranted by the very definition of region itself, a sub-national spatial unit. However, explicit consideration of hierarchical effects in integrated empirical models has lagged far behind theoretical developments that can be traced to early work in central place theory. Of course, the challenge to consider hierarchy with spatial-sectoral-temporal effects provides challenges several orders of more complex magnitude.

In the next section, the topic of integration will be revisited, this time in the context of environmental-economic linkages. The challenges here are enormous and sustained; spatial interaction takes on an important role but it is clear that issues related to spatial scale and linkages mechanisms become even more important.

Environmental-Economic Modeling

Modeling economic and environmental interaction requires taking into account a two-way relationship between the economy and the environment that extend to time and space. Hence, integration is the rule if anything meaningful is to be derived from analysis of environmental impacts on an economy. Usually an increase in industrial activity leads to an increased pollution with immediate and/or latent effects on various locations and milieus, a change in environmental conditions at a certain location affects welfare and economic activity in the region and extends to other regions as well, so understanding the relation economy-environment allows for a better capacity to forecast and assess the effects of environmental policies on the economy and the state of the environment.

Various approaches are available to model the interaction between the economy and the environment; however, the focus will be on quantitative and applied approaches because of the need to develop integrated tools and methods that account for the interaction between economic activity and environment in time and space. State of the art modeling of the environment-economy interaction involves the impact of the agricultural activity and the environment, and more prevalently the relation of transport infrastructure and its negative environmental impacts.

Agricultural activity depends heavily on the environment and on natural resources; this makes recognizing its full negative impacts on the environment less evident especially the long-run effects. Folmer and Thijssen (1996) survey a wide range of models relating to the short, medium and long run interaction environment-agriculture in the Netherlands. Some of these models are mainly concerned with the ecological sustainability while others are more concerned with economic sustainability. These models are used to test theories, forecasting, analysis and design of policies, and monitoring, depending on the scope of the models; econometric, general equilibrium, and input-output techniques are used. For the Dutch case, the authors suggest that further improvement of existing models should take priority on the development on new ones. However, this is often a less attractive approach since the intellectual rewards for incremental improvements are often viewed pejoratively by scholarly peers.

The negative effects of transport on the environment at the local (noise and landscape deterioration) and global levels (air pollution, and greenhouse effects) are always considered in large investment projects and in various countries taxes on transportation means and energy are used to curb those externalities. Rietveld (1996) argues that very often this is done at the expense of a thorough assessment of the economic gains of such projects and that the positive externalities that transport offers are seldom considered. Rietveld (1996), rightly, considers transport infrastructure as a productive input to address its temporary and permanent effects, more specifically the author addresses the effect of financing of the project from locally levied taxes. The improvement of transport infrastructure is viewed as a positive externality when it leads to a reduction in the cost of transport and its impact on the economic activity and also on the potential use of more efficient transportation means as a substitute to more polluting alternatives. Nijkamp *et al*. (2002), using a more integrated approach, assess the environmental sustainability of current transport schemes in seventeen European countries. They evaluated four scenarios that encompass the spatial, economic, institutional and socio-psychological determinants of passengers' mobility. The findings of Nijkamp *et al*. (2002) are that large-scale changes in energy consumption of future passenger transport systems are a strong possibility and it is expected that a reduction in emissions will occur as a result of efficiency increases in transport systems. For this to be realized the authors put forward the need for a change in both public policy and individual choices.

GIS-based integrated environmental impact application are popular among planners to integrate environmental components in planning and economic project evaluation. For example, Carsjens *et al*. (2003) developed a Dutch GIS-based ***S****trategic* ***T****ool for integrating* ***E****nvironmental aspects in* ***P****lanning* ***P****rocedures* (STEPP) that aims to "improve the quality of physical plans on a local level and to create a basis for communication between disciplines and stakeholders that are dealing with environmental and spatial planning". STEPP that has been used by planners for the development of a new housing project in Goor, Netherlands, while ISOLA, an Environmental Information System (EIS) for data analysis and planning support developed for Modena, Italy (Bonfatti *et al.*, 2003). Other integrated systems include, DESIMA (***DE****cision* ***S****upport for* ***I****ntegrated coastal zone* ***MA****nagement*), displays a distributed information system for coastal zones management in Europe (Eleveld *et al.*, 2003); WadBOS, is an integrated ecological and economic model to manage in time and space the conflicting functions and activities of the Wadden Sea, Netherlands (Engelen et al., 2003); and a groundwater rehabilitation system to asses the impact of various subsidies on farmers' behavior in reducing the use of groundwater coming for the aquifers of Western Mancha region in Spain (Sharifi and Rodriguez, 2003).

The effects of environmental policy on economic activity have been assessed using general equilibrium theory, cost-benefit analysis, and input-output models. Frandsen *et al*. (1996) provide a short description of a CGE model for Denmark; the model is used to analyze the macroeconomic costs of carbon dioxide emission reduction through administrative measures, unilateral energy taxes, and internationally coordinated energy taxes. The analysis shows that Denmark could participate in an international effort to curb carbon dioxide emissions by 25% at the cost of only 0.3% of private consumption economy-wide. The model was used to suggest that complete and multilateral international trade liberalization is advantageous to Denmark; if agricultural distorting policies are eliminated, agriculture related pollution is bound to decline and private consumption increases by 1.7%. If all distorting policies are eliminated the increase in private consumption would be 2.6%.

Aaserud (1996) describes work undertaken by Statistics Norway to asses the costs and benefits of environmental-economic policy, the overall costs to society are measured using a general equilibrium model for the Norwegian economy, while the benefits associated with environmental improvement are compiled and linked to the model. The model integrates various costs and

benefits data from various sources and shows that there are benefits that arise from reduced local pollution levels of SO_2, CO, and NO_x through the imposition of carbon taxes.
Various authors have used input-output models to study the environment-economy relation. Economic change within regions impacts various indicators, but employment usually gets most of the attention. In the context of the Chicago, region a decline in employment was accompanied by an increase in output levels for the period 1970-90 (Israilevich and Mahidhara, 1990, 1991) that Hewings *et al*. (1998) showed to be a rather complex transformations, therefore environmental regulation needs to be carefully tailored to meet the air quality target without unnecessarily slowing the economic activity. Fritz *et al*. (2002) propose tackling the problem using the so-called field of influence approach (Sonis and Hewings, 1992) to identify the changes in the input-output table coefficients that produce the largest change on the sectors' pollution multiplier. At the regional level Gørtz (1996), analyses the regional of the effects of taxes on carbon dioxide emissions. The results show that because of the limited share of the energy costs in total costs for an average Danish firm, however the tax burden is heavier on regions with industries largely depending on energy. While regions relying heavily on labor would be better off if the tax system is restructured away from a high level of income tax.

Møller (1996) presents a Danish model that forecasts energy consumption and emissions in the production sector; this is a sub-model of another macroeconomic planning model that analyses emission effects of various policies. The model derives projection of emissions from economic forecasts, but this does not account for feedbacks from emissions to the economy. Although the model represents certain limitation (the feedback effect and limitation to the production sector) it is useful for a wide range of analysis applications. Ramjerdi and Rand (1996) present another forecasting model to describe the effects of carbon dioxide tax on the passengers transport sector in Norway. A scenario based analysis shows that in the long run the effect on the tax on fuel use and emissions can be substantial but without affecting the volume of use by passengers. The tax leads to a change in behavior regarding cars ownership and the choice of transportation means.

Pedersen (1996) addresses problems encountered when trying to put a monetary value on environmental effects, the author argues that the national accounts can be of use only to a limited degree. The author suggests constructing a link between the environmental information expressed in physical units and the economic activity expressed in monetary units represented in input-output systems, the linking procedure is based on the proportionality of the inter-industry exchanges. The author considers three types of emissions, CO_2, SO_2, and NO_x.

At the regional level, models addressing the effects of the economy on the environment deal with set-aside land (Groes and Mohr, 1996) and tax on fertilizers (Jensen and Stryg, 1996) reveal that for the case of Denmark a flexible policy taking into account the location of the set-aside promote environmental gains. As for the direct effects of tax fertilizer they depend on how heavily the region is dependent on the agricultural activity.

The techniques used in integrated economic-environment models are based on existing theories and models such as input-output models, national macroeconomic models, and general equilibrium models so the major innovation comes from finding ways to integrate the models with environmental questions at various spatial levels. At this point there is a need for a greater integration of the environmental and economic components within a given model at various levels of analysis, sectoral and spatial. Further consideration needs to be given to the fact that many pollution sources are mobile, further complicating the modeling of their impacts across economies (or even within large metropolitan regions).

Integration of Models: Some Examples

To conclude this review, and to illustrate some of the problems, perspectives and insights from a model integration system in progress that combines econometric-demographic-input-output with spatial interaction models and environmental systems an example will be provided. It draws on some current work in the Northeast of Brazil, a region that is one of the least prosperous in Brazil and is plagued by water resource allocation problems, problems that are further compounded by climate change. Two research projects are exploring complementary aspects of the allocation problem. A team lead by climate modelers and water engineers is developing a decision-making system for optimal use of water under climate uncertainty; one of the major problems is the optimal storage problem since water is used for hydroelectricity generation. Hence, release of too much water in one year for agricultural, industrial, tourism or household uses may compromise power production the following year if there is a drought. On the other hand, storing too much water creates the possibility of lost revenue in the production sectors.

The second team is exploring optimal water allocation among sectors and major users given some intertemporal optimization objective function that maximizes regional value added.

<<insert figure 3 Brazil example>>

Figure 3 illustrates the process; at the present time, there are two outstanding linkages to be completed. The first will link climate uncertainty to the intertemporal optimization system; the second will expand the water allocation module to consider the movement of water over a pipeline network in the region to explore potential spatial as well as sectoral reallocation options. Of course, there is a further overarching need, namely to include consideration of environmental costs from alternative allocation schemes as well.

The Brazilian case study provides one example of a significant problem – integrating across different geographies that may not only be different in spatial representation in terms of area but also in type (i.e., nodes rather than areas). In the Chicago region, an attempt is being made to address this problem in linking econometric and environmental models. Economic shocks are handled through an econometric-input-output model (see Israilevich et al., 1997) and then transformed into pollutant generation. However, this model cannot provide the spatial distribution of these pollutants and alternative systems are being integrated to capture the spatial distribution of pollution across the metropolitan region. Further, there is a problem with the spatial distribution of economic impacts, especially when consideration of the differential impacts of employment, income generation, and consumption activities are likely to be different within a metropolitan region (see Hewings et al., 2001). Several methods are currently being evaluated, ranging from simple proportional allocations to the use of the spatial diffusion model using spatial statistics and the SEED model (Soot and Sen 1991). The latter model is rooted in the gravity model where labor and job availability measures are estimated iteratively, and the probability of moving is comprised of several separation measures.

This particular project illustrates the new thinking that Isard et al., (1998) have proposed in the updated channels of synthesis chapter; here, Isard *et al*., promote consideration of the analytical hierarchy process of Saaty (1996) to provide a more consistent framework to handle competing objectives and outcomes. Whether this turns out to a be a preferred methodology for handling both qualitative and quantitative competing outcomes, the need to consider frameworks that further process outcomes from integrated models into a more policy-friendly format is becoming even more important as the complexity of the models increases.

Summary Evaluation

While enormous progress has been made in integration and linkage of models, theoretical developments have once again outstripped the ability of the research community to empirically implement the newer, more sophisticated versions of models that have been proposed. Further, the external environment has changed just as dramatically; with accelerated developments towards freer trade between nations, the positions of regions within countries has changed. Many regions are as involved in international trade as they are with domestic trade; tensions arise as national laws promulgating free trade are found to have significantly different impacts on the constituent regions of some countries (see Haddad, 1999).

There are many issues that have not been given greater attention in the development of some of these integrated models. They are simple, but profound issues – model validation, model testing, parameter sensitivity/stability and the tension between parsimony and complexity in the construction of models. Many large-scale systems have gained an unqualified acceptance whereas scholars should have been more circumspect in articulating the restrictiveness of some of the assumptions employed. In the computable general equilibrium literature, there has been extensive borrowing of parameter estimates from one model to another; these techniques serve to complete a model but raise questions about the role they play in outcomes with important policy implications. What is required is some careful evaluation of the parameter spaces and their role in changing results; this work is less glamorous than extending the scope and depth of an existing system but it is important in two senses. First, it will provide some sense about what is analytically important in the model structures and, through this explorations, it will help target future research efforts. There is a still a sense that the linkages between integrated models remain the most sensitive but this may not turn out to be the case when sufficient testing has been accomplished.

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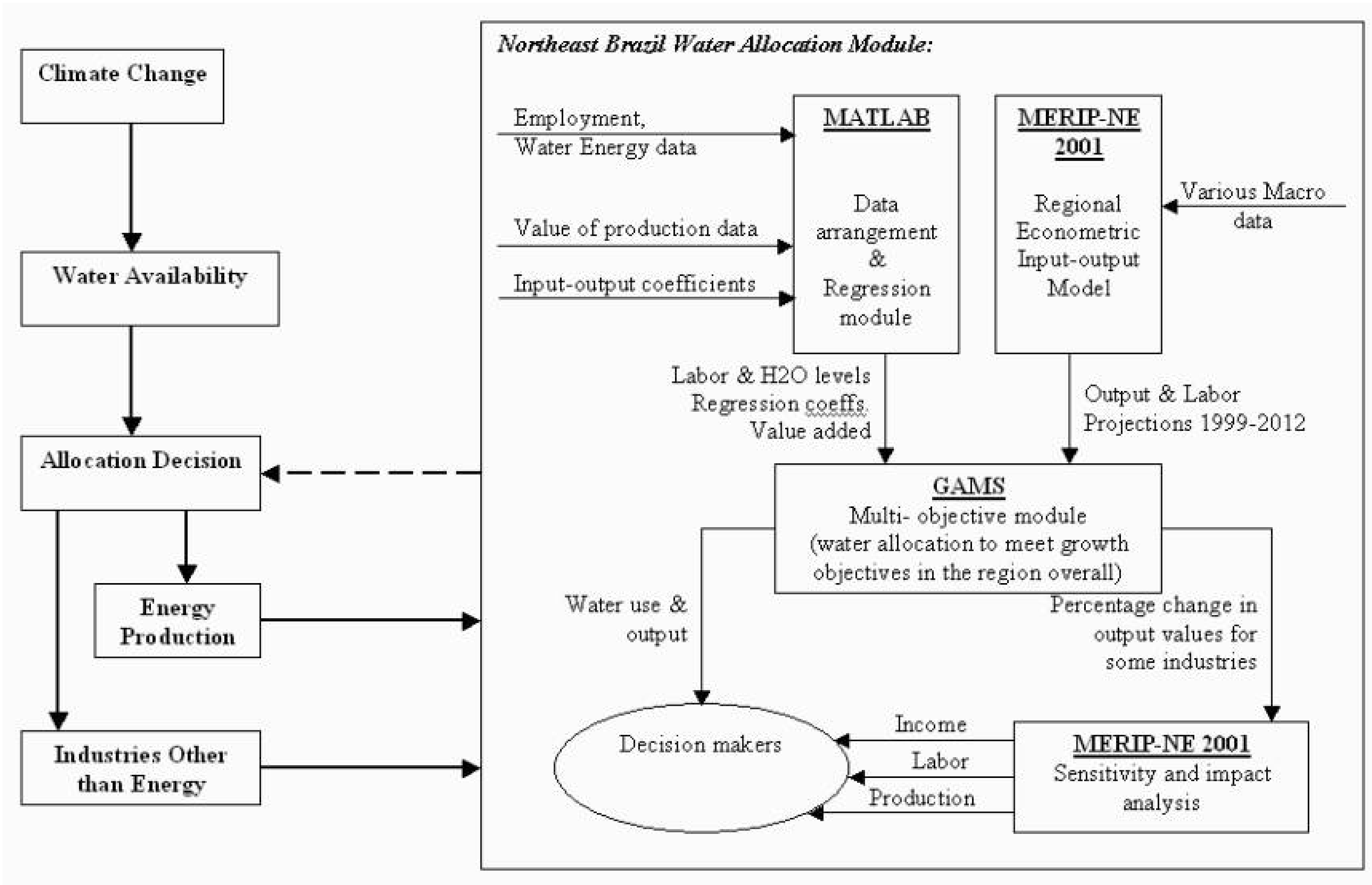

Figure 3: Integrated Model for Assessment of Water Allocation in NE Brazil