# LINKING CROSS-IMPACT PROBABILISTIC SCENARIOS TO WORLD SOCIAL ACCOUNTING MODELS

**EMILIO FONTELA**

**UNIVERSITY ANTONIO DE NEBRIJA (SPAIN)**

**JOSÉ M. RUEDA-CANTUCHE**

**PABLO DE OLAVIDE UNIVERSITY (SPAIN)**

## 1. INTRODUCTION

Since the early nineties, with the first Earth Summit held in Rio de Janeiro in 1992, the promotion of a global consciousness over the human impact on climate and over the unsustainability of economic and social development has been one of the most important features achieved by the global community. However, there is a widely shared agreement with respect the failure of the overall performance regarding the established goals. Within this context, as Duchin et al (2002) stated, more than ever there is a need to articulate a clear approach to sustainable development in its social, environmental and economic dimensions on the basis of the exploration of alternative paths capable of modifying significantly the present structure on a global level.

World modelling plays an important role on this issue. Since the pioneering works of Forrester (1971) and Meadows et al (1972) for the first report to the Club of Rome, the Leontief (1974) and Leontief, Carter and Petri (1977) world models constitute important large-scale modelling efforts, both of which were input-output based analysis. That is, the model was built around a fictitious case of two regions (developed and less developed countries), three different kind of commodities (extraction industry products, other production and pollution abatement services), two components of final demand (domestic and trade) and two components of value added (labour and capital returns). All theoretical basic input-output relations hold regarding the quantity model and its dual price model. With more unknowns than equations, the model was roughly estimated in a scenario framework for the year 2000, where different values were assigned to those variables considered as exogenous. A comparative of these results with actual 2000 data were described in Fontela (2000). At the same time, authors such as Stone (1976) considered feasible to develop a world model based on national accounting data, including sectoral disaggregation. But unfortunately, United Nations lost progressively its interest for global models in the benefit of more local and national solutions based models (e.g. LINK project). Oil shocks, currency fluctuations and an increasing dissatisfaction with long-term future models together with a high level of unwarranted subjectivity of the model builders may have been the reasons why little interest has been paid on world modelling during the eighties and the nineties.

But since the late nineties, there is an increasing consciousness over the process of globalization all around the world. International organizations, anti-globalization movements and sustainable growth promoters, financial communities and multinational corporations now elaborate their strategic plans in a global level. Therefore, we argue that somehow the time is right again to continue the research lines initially proposed by Leontief (1974) and recently addressed by Duchin and Lange (1994). Presently and differently from the seventies, there are several reasons that encourage building world models, i.e. the continuously improving database for each country within the context of international statistical systems (System of National Accounts; European System of Accounts and System of Environmental Accounts); the increasing elaboration of input-output tables on a use-make framework by a larger number of countries; the availability of economic time series for regions; and the development of social accounting matrices, computable general equilibrium models and new tools to be incorporated in such world models regarding private consumption coefficients (behavioural equations), technical coefficients (technology), and scenarios (cross-impact analysis or interpretive structural modelling).

The input-output structural framework allows us to portray the “real” side of the economy and to analyze structural change at a national or regional level. Initially, it was conceived for production technologies but it has been extended to household lifestyles and income distribution patterns. Also, input-output based models can be used for assessing the impact of human activity on the environment in terms of utilization of resources and the generation of waste and pollutants. As a result, input-output analysis is playing an increasingly important role on global issues and diverse environment and social impact assessments. Presently, there is a further interesting work being done by Meyer, Lutz and Wolter (2003). Hence, the input-output framework should be crucial for incorporating global concerning issues related to financial (World Trade

Organization, International Monetary Fund), informational (genetic and medical information), cultural (clashes of cultures, cultural invasions) and institutional (labour/children rights, rights of knowledge and patents) domains as parts of the new global order that is emerging in this century.

Duchin et al (2002) urge to construct scenario-based input-output models of the global economy supported by the whole input-output community and launched in the International Input-Output Association. This would involve a major effort towards new theoretical modelling, policy relevance and an organizational set-up. From a theoretical point of view, global models are indeed a platform for integrating results and insights from many disciplines and fields of research. Then, a knowledge-based network of professionals with competence (epistemic community) would be required (from, for instance, ecological economics, industrial ecology, energy economics, sociology and anthropology). Not only are economists or economic theorists called for but social scientists, policy makers and involved members and institutions of civil society as well. Besides, confrontation should be avoided within the various parts of the input-output based research communities such those working with social accounting matrices, computable general equilibrium models and dynamic input-output analysis. Further organizational steps to construct a scenario-based input-output world model can be seen in Duchin et al (2002) being far beyond the scope of this paper.

Consequently, a model for the world economy should be embedded in an input-output structural framework where futures-inspired scenario analysis can be carried out to provide insight as to what the future may have in store and to our capability for assessing impacts in crucial areas, by doing comprehensive research of possible implications of different courses of action to be followed.

## 2. SCENARIO MODELS OF THE WORLD ECONOMY

Economic models include theories about the performance of the main relationships over time among the critical features that characterize the reality to be modelled (mental models). Also, economic models include mathematical descriptions of these theories in a concise notation, where features become variables to be measured, being them later related in equations through parameters.

Bearing this in mind, an economic model should faithfully represent the underlying theory, be able to test it and serve to analyze scenarios relevant to contemporary problems for which theory is still lagging (Duchin et al, 2002). Within this context, the main motivation of building a world economy model would be then to assist in the development of theories, to test them and to explore the future using scenario-based analysis. We should be aware of the required database efforts, the scenarios development requirements and the need for a systematic interpretation of the corresponding results.

A model of the world economy should include theory, scenarios, data, model and interpretation with, where possible, some additional ongoing feedback among them. Let us focus on the scenario issue. The correct design of different types of scenarios is a matter of interdisciplinary challenge that usually implies some collaboration between economists and futurists. Moreover, the main problem relies on the necessary translation of these scenarios into the corresponding values of variables and parameters included in the model. For instance, as in most of all modelling efforts of the seventies, the Leontief input-output static model (Leontief, 1954) failed to explore the future due to its lack of reaction to prices and technological change. To solve this handicap, dynamic input-output and behavioural microeconomics were included in existing multisectoral and computable general equilibrium models so that technical change would be considered as endogenous instead of exogenous. Hence, there is no doubt that closing input-output models in such a way will lead to inspire global modelling. In most cases, scenarios are reduced to a small number of figures before the formal analysis is carried out. Nevertheless, a new and more comprehensive approach to scenarios is needed.

Futures research, as provider of objectives for optimal long-term decision-making, consolidated in the seventies around experts' opinions about the future (Delphi and brainstorming tools), relationships knowledge between future events, trend and actions (cross-impact analysis and system dynamics instruments), structural portraits of complex ill-defined systems (morphological analysis and interpretative structural modelling), and alternative futures descriptions (scenario writing tools). More recently, this discipline has evolved from the initial ideas of forecasting into the notion of providing inputs to policy making (Godet, 1993). According to Duchin et al (2002), the specific methods of futures research rely upon the analysis of complexity (morphological analysis, systems functions and identification of structures), the study of behaviour of agents and of their decision-making processes, the study of processes for expert consensus development (Delphi and cross-impact analysis), and the scenario building, for which a set of approaches are assumed for the consideration of evolution, simulating behaviours of agents under new constraints and situations. Eventually, applied futures research has been mostly focused on exploring futures of economic agents, nations but rarely on a global level.

The possible relationship between futures research and economic modelling in the context of input-output based world models can be seen as follows. Let us think of an economic system (endogenous variables) and all their social, environmental, political, cultural, etc, interactions (exogenous variables). A social accounting matrix would cover quite consistently the different relationships between the several components of the economic (and also in a sense, social) system (production, income and accumulation processes). Some interactions of economic sectors with e.g. environment can be quantified as in Duchin and Lange (1994) with respect to natural resources consumption or emissions of pollutants. But in the present stage of our knowledge, the interactions between those non-economic global features and its translation to economic impacts are certainly non-quantifiable. We argue that this is the best area for futures research such as Delphi, cross-impact and interpretive structural modelling methods. Then, if we want to link futures research to input-output modelling, both a formal model and a method to develop scenarios should be jointly incorporated, being the cross-impact analysis the best method, we argue, to provide us with expert opinion about the change in a priori probabilities of the scenarios considered.

## 3. CROSS-IMPACT PROBABILISTIC ANALYSIS

According to Fontela (2002), if a major purpose of social science would be the improvement of decision-making processes regarding social issues, then methods of integrating opinions about global systems with knowledge of the functioning of given subsystems of the same reality are needed. In this respect, cross-impact analysis is an embryonic method of potential interest.

Initial cross-impact approaches were originally developed with the aim to overcome the lack of explicit consideration of the possible links between the forecasts, which was one of the main handicaps of the Delphi method. Pioneering works regarding the idea of building a matrix connecting different events are Helmer (1972) and Dalkey (1971).

### 3.1 Cross-impact method

Let $E_i$ be the *i*-th event and $\overline{E}_i$ its complementary event. Then, accepting $P$ as a probability function assuming the Kolmogoroff axioms of certainty, additivity and non-negativity, we can establish the following four constraints:

(1) All probabilities are between zero and one, both included.

(2) $P(E_i / E_j)P(E_j) = P(E_j / E_i)P(E_i) = P(E_i \cap E_j).$

(3) $P(E_j) + P(E_i) - P(E_i \cap E_j) = P(E_i \cup E_j).$

(4) $P(E_i \cap E_j) + P(E_j \cap E_k) - P(E_i \cap E_k) \leq P(E_j).$

Given the first three constraints, it can be proved that the following partition matrix (see Figure 1) can be constructed for two events dealing with the occurrence (1) or non-occurrence (0) of events $E_i$ and $E_j$, respectively. Hence, given the absolute probabilities of both events and their corresponding conditional probabilities, if we happen to dispose of three of them, then the fourth is thereby determined. But in case we have only two of them, the two others must lie within certain limits, which can be derived from the three first constraints. These limits are the following:

(a) $P(E_j) + P(E_i) - P(E_j)P(E_i / E_j) \leq 1.$

(b) $P(E_i)P(E_j / E_i) \leq P(E_j)$ or $P(E_i)P(E_j / E_i) \leq P(E_i / E_j).$

**Figure 1 Partition matrix**

| $E_i$ \ $E_j$ | 0 | 1 | |
|---|---|---|---|
| 0 | $P(\overline{E}_i \cap \overline{E}_j)$ | $P(\overline{E}_i \cap E_j)$ | $P(\overline{E}_i)$ |
| 1 | $P(E_i \cap \overline{E}_j)$ | $P(E_i \cap E_j)$ | $P(E_i)$ |
| | $P(\overline{E}_j)$ | $P(E_j)$ | 1 |

The fourth constraint is only required when more than two events are considered. It implies that the probability of an event has to be larger than the sum of the probabilities of occurrence of $E_i$ and $E_j$, and $E_i$ and $E_k$, respectively, minus the probability of occurrence of the two other events $E_k$ and $E_j$. The complete generalized version for more than two events can be seen in Fontela (2002).

Let us assume now that a group of experts are asked for initial probabilities of different events and for their respective conditionals or impact factors. Later, we would assume that an average of the answers will represent the view of the group. It is straightforward that no conditional probability constraints have been taken into account so far. Therefore, nothing guarantees the fulfilment of the four constraints outlined above. In order to bear these restrictions in mind, the sum of the quadratic differences between the estimates (averages) and the corrected values for absolute and conditional probabilities is usually minimized subjected to the four constraints just mentioned. The optimization problem would be postulated as follows:

$$
\begin{aligned}
&Min \sum_i \left[ \left( P(E_i) - P^*(E_i) \right)^2 + \left( P(E_i/E_j) - P^*(E_i/E_j) \right)^2 \right] \\
&subject\ to: \\
&(1)\ 0 \le P(E_i) \le 1, \text{ for all } i. \\
&(2)\ P(E_i/E_j)P(E_j) = P(E_j/E_i)P(E_i) \\
&(3)\ P(E_i) + P(E_j) - P(E_j)P(E_i/E_j) \le 1 \\
&(4)\ P(E_i \cap E_j) + P(E_j \cap E_k) - P(E_i \cap E_k) \le P(E_j).
\end{aligned}
$$

Final results would provide the probabilities of the different states of the system in which some events have or not occurred. This is described in futures research literature as “scenarios”. For instance, in global modelling we can consider three different kinds of events, namely new more restrictive international pollution abatement policies ($E_1$), major income distribution changes in order to diminish income differences between less developed and developed countries ($E_2$), and relevant technological progress with sizeable costs reductions ($E_3$). Then, we have eight possible scenarios depending on the number of these events that actually happens.

Once events have been considered in a cross-impact analysis, we must make a translation of each event into a given set of values for the exogenous variables, coefficients and even equations of the model; also, the combination of events may incorporate several different behaviours of the corresponding variables, coefficients and equations. These transformations are not easy task. Only few exceptions address these issues (Sallin-Kornberg and Fontela, 1981).

## 4. INPUT-OUTPUT BASED WORLD MODELS

A model of the world economy needs credibility from academic economists, social scientists and modellers to advance the theoretical basis of the model, and from policy makers, activists, researchers, businesses and society at large to improve decision-making processes. Furthermore, these two disjunct groups should be met in a balanced way so that the model would create a platform for the interaction between them.

According to Duchin et al (2002), the Leontief's world model is the strongest point of departure of world modelling. However, it should be completed with a more comprehensive conceptual and theoretical scope. Selected key features of the world economy should be included in the core of the model representing the global economy: financial flows, flows of commodities and services, the exchange of currencies, the generation and distribution of income, technology transfer (production) and lifestyle emulation (consumption). Also, the needed requirements from economists, statistical offices, mathematicians and futurists should be laid out, namely on technology transfers or lifestyle consumption.

A world model should faithfully portray the circular flows linking production, income, consumption and accumulation; and precisely, input-output and social accounting matrices (SAM) provide a detailed and a graspable description of the structures of these components at a national/regional scale. Therefore, a world model could be based on a global social accounting matrix (see Table 1).

**Table 1 Aggregate SAM**

| | Production | Income | Accumulation |
|---|---|---|---|
| Production | I/O | C | I |
| Income | Y | D | |
| Accumulation | | S | F |

Fuente: Duchin et al (2002).

In Table 1, I/O represents the relations between the components of productions (input-output subsystem); D stands for the processes of income distribution; F describes the processes of financial operations or financial flows; C, consumption; I, investment; Y, income; and S, savings.

Evidently, to begin the discussion over the possible answers to those global concerning issues like, for example, sustainable development, a more detailed SAM would be needed. This is not only referred to a sectoral disaggregation but to households (Duchin, 1998), institutions or factors of production.

**Table 2 A two region world SAM**

| | | Activities | | Factors | | Institutions | | Accumul. | | Trade | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | |
| Activities | 1 | $A_1$ | | | | $C_1$ | | $I_1$ | | $E_1$ | | $x_1$ |
| | 2 | | $A_2$ | | | | $C_2$ | | $I_2$ | | $E_2$ | $x_2$ |
| Factors | 1 | $F_1$ | | | | | | | | | | $f_1$ |
| | 2 | | $F_2$ | | | | | | | | | $f_2$ |
| Institutions | 1 | | | $W_1$ | | $T_1$ | $T_{12}$ | | | | | $c_1$ |
| | 2 | | | | $W_2$ | $T_{22}$ | $T_2$ | | | | | $c_2$ |
| Accumul. | 1 | | | | | $S_1$ | | $K_1$ | $K_{12}$ | | | $i_1$ |
| | 2 | | | | | | $S_2$ | $K_{22}$ | $K_2$ | | | $i_2$ |
| Trade | 1 | $M_1$ | | | | | | | | $B_1$ | | $r_1$ |
| | 2 | | $M_2$ | | | | | | | | $B_2$ | $r_2$ |
| Total | | $x'_1$ | $x'_2$ | $f'_1$ | $f'_2$ | $c'_1$ | $c'_2$ | $i'_1$ | $i'_2$ | $r'_1$ | $r'_2$ | |

A schematic representation of a world SAM is provided in Table 2. For *n* sectors, *k* factors, *m* institutions and *p* types of accumulation, the dimensions of the matrices shown in Table 2 are given by A($n$x$n$), F($k$x$n$), C($n$x$m$), W($m$x$k$), T($m$x$m$), I($n$x$p$), S($p$x$m$), K($p$x$p$), E($n$x1), M(1x$n$), B(1x$p$), $x$($n$x1), $f$($k$x1), $c$($m$x1), $i$($p$x1) and $r$(1x1).

Let us consider advances industrial countries (AIC) and developing countries (DC) such as two regions. In this case and for each region, the A matrices represent the intermediate uses by sectors; the C matrices describe domestic consumption by households; the I matrices stand for domestic investments; the E matrices, for export vectors among each other; the F matrices represent the earnings of factors of productions; the W matrices, the allocation of income from factors of production to households; the $T_1$ and $T_2$ matrices describe redistribution of income between domestic institutions; the $T_{12}$ and $T_{21}$ matrices, on the contrary, the institutional income transfers from DC to AIC and vice versa; the S matrices, the savings by households; the $K_1$ and $K_2$ matrices represent changes in financial assets; the $K_{12}$ and $K_{21}$ matrices, in contrast, capital flows from DC to AIC and vice versa; the M matrices stand for imports vectors among each other; and the B matrices describe the borrowing/lending to cover for the trade deficit/surplus of AIC and DC. Notice that the sum of both the components of $B_1$ and $B_2$ should be null. The same is applied for the sum of $K_{12}$ and $K_{21}$ components.

Let us assume that we have already built a world SAM such as shown in Table 2. Usually, production and income are treated as endogenous variables whereas accumulation is treated as exogenous. Within this framework, we will be able to use this extended input-output model relating financial flows to production and income distribution and, consequently, to environment and social issues (e.g. world sustainability), since production are closely related to the latter. But however, from a futures research point of view, capital transfers should be considered as well endogenous, leaving those institutional, political, technological, social, environmental and cultural dimensions as exogenous.

Lastly, if a world SAM becomes a part of a wider futures research programme, we could apply firstly Delphi or morphological analysis to identify future technical developments affecting the production system; secondly, we could apply interpretive structural modelling to extract the relevance tree of the content of declarations made by observers of the world system, such as United Nations, Club of Rome, political leaders, and so on; then, use cross-impact analysis to measure a priori subjective probabilities of the future political events considered by expert analysts at a world scale; and finally, combine the previous results into a comprehensive and participative scenario writing, including various alternatives for policy making. Eventually, a new generation input-output based world model will be the most suitable tool for analysis, simulation and decision-making at world level.

## 5. CONCLUDING REMARKS

Since the pioneering contribution by W. Leontief in his 1973 Nobel Prize lecture (Leontief, 1974) input-output models have been often associated to world models attempting to estimate global environment impacts of economic growth. In their United Nations research project, Leontief, Carter and Petri (1977) introduced also the concept of scenarios regarding possible future developments of the world economy, and used their input-output models to quantify the environmental impacts and related economic consequences. In this context, scenarios were somewhat connected with expert opinions, which quite often lack of solid scientific knowledge. However, if a major objective of social science is to improve decision-making processes related to social issues, we need methods for integrating these expert opinions about the global systems with the knowledge of the functioning of given subsystems of the same reality. In this sense, cross-impact analysis becomes an embryonic method of potential interest.

Both cross-impact analysis and the Delphi method aim to obtain probabilistic assessments of future events by groups of experts. Nevertheless, the latter method fails to consider explicitly the existence of links between forecasts. It is felt that if some events considered in a Delphi exercise should actually take place, the probability of others could be affected. Therefore, the need to take these possible impacts into consideration led to the idea of building a matrix connecting the different events, as cross-impact analysis does. The cross-impact matrix was originally used by O. Helmer and T. J. Gordon in a study for Kaiser Aluminium Co. in 1966, was first reported by T. J. Gordon and H. Hayward in the December 1968 issue of Futures, and further developed by Fontela and Gabus (1974).

More recently, in the context of environmental global modelling, there is an increasingly interest for the possibility of linking scenarios as “written narratives” to world models, and eventually a priori probability assessments to quantitative econometric models (Fontela, 2000; Fontela, 2002).

In conclusion, this paper has been concentrated on the possibility of linking cross-impact methods for probabilistic scenarios with world input-output models including environmental issues, with the main purposes of improving global decision-making processes towards sustainable development and other issues that are placed at the centre of society’s concerns, and of being capable to advance future events and future impacts of human activity on the global economy and society at large.

## REFERENCES

Dalkey, J., (1971), *An Elementary Cross-Impact Model*, RAND report r-677.ARPA.

Duchin, F., (1998), *Structural Economics. Measuring Change in Technology, Lifestyles and the Environment*, (Washington, D.C.: Island Press).

Duchin, F., Fontela, E., Nauphal, K. and Pulido, A., (2002), Scenario Models of the World Economy, *Cuadernos del Fondo de Investigación Richard Stone*, November, 7.

Duchin, F. and Lange, G.M., (1994), *The Future of the Environment, Ecological Economics and Technological Change*, (New York: Oxford University Press).

Duval, A., Fontela, E. and Gabus, A., (1975), *Cross-Impact Analysis, a Handbook on Concepts and Applications in Portraits of Complexity, Application of Systems Methodologies to Societal Problems*, A Battelle Monograph no. 9, Columbus, Ohio.

Fontela, E., (2000), Bridging the gap between scenarios and models, *Foresight*, 2, 1, pp. 10-14.

Fontela, E., (2002), Cross-impact analysis and structural economic models, International Conference on Input-Output Techniques, Montreal (October 10-15).

Fontela E. and Gabus, A., (1974), Events and Economic Forecasting models, *Futures*, 6, 4, pp. 329-333.

Forrester, J.W, (1971), *World Dynamics*, (Cambridge, Mass.: Wright-Allen Press).

Godet, M., (1993), *From Anticipation to Action: A Handbook of Strategic Prospective*, UNESCO, Paris.

Helmer, O., (1972), Cross-Impact Gaming, *Futures*, Vol. 4, 2, pp. 149-167.

Leontief, W., (1954), *Studies in the Structure of the American Economy*, (New York: International Arts and Sciences Press).

Leontief,W., (1974), Structure of the World Economy, *The American Economic Review*, December, LXIV, 6, pp. 823-834.

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

Meadows, D., Randers, J. and Behren, W.W.III, (1972), *The Limits to Growth First Report to the Club of Rome*. (New York: Universe Books).

Meyer, B., Lutz, C. and Wolter, M. I., (2003), Global Multisector/Multicountry 3 – E Modelling: From COMPASS to GINFORS, *Paper* presented at the 2003 Berlin Conference on the Human Dimensions of Global Environmental Change, Berlin, 5-6 December.

Sallin-Kornberg, E., and Fontela, E., (1981), Scenarios building with the Explor-Multitrade 85 Model, in *Commerce mondial et modèles multinationaux, Economica*, Paris.

Stone, R., (1976), Major Accounting Problems for a World Model, *Paper* presented at the Working Seminar on Global Opportunities and Constraints for Regional Development, Harvard University, Cambridge, Mass., Feb.18-22, mimeo.