Leontief and the Future of the World Economy

Emilio Fontela

Abstract

The world model was designed by Leontief as a tool for exploring the future of the world economy. This paper reviews the process of design and calibration of this model, and the main simulation runs that were performed in the early 1970s looking towards 2000. The results of that scenario are compared with observed developments during the period. An agenda is provided for further research in this area with models incorporating input–output tables and the new scenario's methodologies.

Keywords: world modelling, scenario, long-term exploration, alternative futures

Emilio Fontela is honorary professor at the University of Geneva, and associate professor at the Universidad Autónoma de Madrid.

Emilio Fontela
Instituto L.R.Klein (Centro Stone)
Carretera de Colmenar km.15
28049 Madrid
Tel. +34913975079
Fax: +34913973943
e-mail: <emilio.fontela@uam.es>

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1. Historical background

In the 1950s and 1960s, the world economy showed extremely high growth, reaching, on average, an annual gross domestic product (GDP) growth rate of 4.5%. This high economic growth raised problems of sustainability, taking into account the increase in pollution and the significant consumption of finite resources such as minerals and hydrocarbons. At the end of the 1960s, a thorough analysis of these problems was greatly stimulated by the Club of Rome's active promotion of a world model using systems dynamics methodologies. The model was first developed by Forrester (1971) and expanded by Meadows, Randers and Behren (1972). The latter study, entitled "Limits to Growth", pointed quantitatively to the impending dangers of world shortages of energy and raw materials, and to vast environmental problems, should the world population, capital formation, and economic production continue to grow exponentially at rates such as those observed in the preceding decades.

Systems dynamics deals with "multi-loop non-linear feedback systems, a class to which all our social systems belong" (Forrester, 1971, p. 123). The design of the model was fairly simple, the world being treated as a single unit. The structural specification and calibration of the model, however, turned out to be extremely difficult due to a lack of relevant information. As a consequence, arbitrary levels and rates had to be used for most variables. Despite the efforts of a better quantification by a larger research team, the resulting final world model raised considerable objections. Yet, the debate in itself served the purpose of diffusing the Club of Rome's idea of the "World Problematique".

Substantial improvements in the methodology and data were introduced in a second report to the Club of Rome by Mesarovic and Pestel (1974). Although they used a set of interacting regions of the world—this being the first time that such a model had been employed—the nature of the debate on world modelling was not substantially changed. The idea of "Limits to Growth" was also developed by Ward and Dubos (1972) and was presented to the UN Conference on Human Environment (Stockholm, 1972). However, in their study they used other means—such as the biospheric concept of only one Earth.

The UN had been pressing for an international development strategy for the 1970s (see UN, 1971). In particular, the UN wished this strategy to aim at reducing the disparities between rich and poor countries, and to take account of the new consciousness of the limited capacity of the Earth. The interesting progress of modelling these relevant topics moved the UN to launch a study dealing with environmental issues raised by world development and looking for "possible alternative policies to promote development while at the same time preserving and improving the environment" (UN, 1973, p. 2). To embark on such a study, the UN required a solid methodological basis. Wassily Leontief, who had already analysed the relations between the economy and the environment (Leontief, 1970), had a long-standing relationship with the UN organisation (having hosted the International Conferences on Input–Output Techniques in Geneva in the 1960s). Leontief was therefore the UN's first choice.

Leontief was enthusiastic about the UN project and, by 1973, he had already developed his first theoretical model. This model provided the content for the Stockholm lecture of December 1973, when he received the Nobel Prize in Economic Science (Leontief, 1974). The model was built around a hypothetical case of two regions (developed and less-developed countries), three commodities (the product of the extraction industry, other production, and pollution abatement), two components of final demand (domestic and trade), and two components of value-added (labour and capital returns). Its theoretical formulation included both a quantity model and a dual-price model, relying on the basic input–output relations.

With 17 equations and 29 unknowns, this simple model required 12 exogenous values for actual computation. The choice of these values, as well as possible changes in technical coefficients, was made in the framework of scenarios. Peter Petri provided rough estimates of the necessary technical coefficients. "The numbers are, strictly speaking, fictions. But their general order of magnitude reflects crude, preliminary estimates … " (Leontief, 1974, p. 825). On this basis, three scenarios were computed for 2000.

In the base scenario (Case 1), the productivity of labour was expected to be three times as high in 2000 as in 1970, and the developed region would strictly enforce the standards of the 1967 US Clean Air Act, whereas there was to be no abatement activity in the less-developed region. In Case 2, the less-developed region would introduce an abatement policy to limit pollution to twice its initial level. In Case 3, the productivity of labour in the extraction industry of the developed countries would grow at half the initial rate, and the technical coefficients for inputs in this extraction industry were to be doubled. This reflected a move towards exhaustion of natural resources and to increasing extraction costs. As might be expected in a simple linear accounting system, without price-sensitive behavioural equations either for demand or for trade, the results of the three scenarios in real terms were not radically different. However, in Cases 2 and 3 there was a substantial shift of the terms of trade—leading to a redistribution of income favouring the less-developed countries.

Leontief (1974, p. 833) ended his Nobel lecture by stating:

> All theories tend to shape the facts they try to explain; any theory may thus turn into a Procustrean bed. Our proposed theoretical formulation is designed to protect the investigator from this danger: it does not permit him to draw any special or general conclusions before he or someone else completes the always difficult and seldom glamorous task of ascertaining the necessary facts.

This less-than-glamorous task was expected of Anne Carter, Peter Petri and, of course, Wassily Leontief himself during the following two years. It led to the report to the UN on the

Future of the World Economy (UN, 1976)—which was later to be published in book form in several languages (Leontief, Carter & Petri, 1977). It was widely discussed in both developed and developing countries, by all sorts of economic and environmental organisations.

Before its release, the report was discussed by an *ad hoc* group of experts (Chakravarty, Courcier, el Iman, Klein, Linneman, Mesarovic, Porwit, Ridker, Shishido, and the present author) that proposed further extensions of the model and the consolidation of permanent UN activity around it, under the heading of 'UN Project 2000'. This was in line with Leontief's own wishes: "It is hoped that the model will have a continuing life in which fresh data are used as they become available and in which the model is eventually applied to other development questions" (UN, 1976, p. 7).

Earlier in that same year, Richard Stone (1976) had confirmed that developing a world model based on national accounting data, including sectoral disaggregation, raised "serious but not in principle insoluble" problems. As Stone (1976, p. 32) observed:

> In so far as they are due to the uneven development of the relevant subject areas, all that is needed is for the interest and energies of social scientists and historians to be channelled towards a quantitative approach to their subject: once these scientists had set up the appropriate framework, the data will flow in like pins towards a magnet, as has happened with national accounts statistics in the last thirty years.

Some UN agencies, such as the United Nations Industrial Development Organization (UNIDO), made efforts to develop and quantify new generalised world models, The Seventh International Input–Output Conference, held at Innsbruck in 1979, devoted an entire session to the discussion of several world models developed by international organizations (UNIDO, 1984).

As often happens in large organisations, the UN was not interested in funding the refinements, the UN agenda changed, and Project 2000 progressively lost momentum. Rather, the UN concentrated on shorter-term macroeconomic analyses implementing project LINK under the methodological guidance of Lawrence R. Klein (Klein & Peeterssen, 1973). In 2002, LINK is still a UN project, coordinated by teams at the Universities of Toronto and Pennsylvania, including a hundred country macro-models interrelated by a trade matrix.

At a later stage, Leontief made further runs with the model (together with Faye Duchin at the Institute of Economic Analysis), dealing with alternative population forecasts and other issues (Leontief, Duchin & Sohn, 1978). Leontief had proven the point—given adequate resources, it is possible and useful to build regionalised long-term world models with the usual restrictions of input–output analysis.

2. The model and the data

The final version of Leontief's world model (UN, 1976) included 15 regions. There were four regions covering the advanced industrial countries, four regions for the centrally planned economies, and two groups of developing countries—namely, resource-rich (three regions) and resource-poor (four regions). Each region was described in terms of 48 sectors of economic activities, including eight exhaustible mineral resources and hydrocarbons. In addition, eight types of major pollutants and five types of abatement activities were identified. The base year was 1970 and projections were made to 1980, 1990, and 2000. In total, the 15 interconnected (through trade) sets of regional equations developed into a linear system of 2625 equations.

In some senses, the world model was a partitioned hybrid input–output system with agricultural crops, energy and minerals treated in terms of physical units and nominal prices, and the rest of the sectors treated in value terms with initial unit prices. An original feature of the model was the use of "world pools" to deal with trade relations. Regions addressed their import requirements (as a function of their own activity levels) to a pool which distributed the totals to the different exporting countries. The world pool idea avoided the need for building an input–output international trade model, with country-to-country flows for each commodity, along the lines initially suggested by Isard (1951). While for Isard (1951, p. 320), "any given good or service produced in any region must be taken as a unique commodity distinct from the same good and service produced in any other region", with Leontief's idea of world pools, goods and services are the same and nothing is required to be known about the bilateral relations between regions. The imports of the different commodities were endogenous, a function of regional outputs. For each commodity, a region could export a fixed proportion of the total world requirements (the sum of country imports). This proportion could be established from statistical observation of past and present situations, or from estimates provided by sectorial experts, as is usually done with columns of technical coefficients in an input–output table.

The resulting trade flows between the region and the pools were valued at uniform world prices (eventually obtained from the dual system of the US model)—a rather crude assumption justified by the lack of relevant international information and the belief that the US economy was the best available example of a free-market international economy.

The behavioural relations were kept very simple, and household consumption of specific goods was allocated with coefficients proportional to the aggregate consumption per capita. 'Slacks' were introduced as extra additive variables in many equations, simplifying the use of the model in alternative situations (for example, changes of variables from endogenous to exogenous and vice-versa, or even changes in the shape of an equation)—an essential requisite for scenario simulation. Despite its comprehensiveness, the model was very simple in its structure and easy to run. The main difficulty lay in establishing a database for 1970, and projecting structural changes into the future.

Because the core of the model consisted of the 15 regional input–output tables, assembling these tables raised many problems. Although input–output tables were available for more than 70 countries, these featured different classifications and prices, and not all of them were for 1970. Therefore, the regional tables were estimated mainly on the basis of cross-national regressions of national income per capita. The regressions used input–output coefficients for the eight countries for which comparable prices were actually available (Kravis 1975). Whenever possible, adjustments were made to introduce regional-specific information.

Considerable attention was devoted to the input structures for mining activities. Starting from the 485-sector US input–output table, the relevant columns were modified to take into account the interregional differences on average costs of extracting each specific resource. US data also helped to establish regional resource consumption coefficients. The structures of the consumption of commodities for 1970 were based on cross-country regressions on income per capita for the countries of the Kravis study. International trade data were obtained from UN statistics, and time series helped to identify trends in the relevant trade import and export coefficients.

The coefficients of this complex system were projected for the years 1980, 1990, and 2000—either as a function of income (per capita or total) or as a function of exogenous techno-economic information. For natural resources, the input coefficients also depended on the difference between production cumulated in the past and assumptions for the existing reserves. These coefficients were expected to increase with the depletion of reserves, thus reflecting the increasing difficulty of extractive activities. Production determined the employment levels as well as the needs for different types of capital stocks. The investment requirements were the sum of the depreciation of past capital stock (that is, replacement investments) and of additional requirements to expand the current capital stock.

Table 1, which is directly extracted from the report, portrays at a glance the variety of the methods that were used to estimate the initial 1970 base and to project the coefficients for the target years.

In Table 1, the first four rows and columns describe the hybrid input–output matrix; the row on pollution records emissions, and the corresponding column records depollution activities; the rows capital and labour decompose value added; final demand includes investment and inventories (gross capital formation), consumption, urban (consumption), and government (private and public consumption), and a specific column treats fisheries exogenously from the production system. Exports and imports close the relations with the rest of the world.

To keep the accounting balances in the projections, scaling procedures were adopted to fit the specific items to the totals. This scaling was either vertical (normalising the inputs to meet the total projected input) or horizontal (normalising the outputs to meet the projected total input).

Table 1

Coefficient Estimation and Projection for a single Region Block												
	Agriculture	**Metals**	**Energy**	**Input-Output**	**Investment**	**Inventory**	**Pollution**	**Consumption**	**Urban**	**Government**	**Fish**	**Exports**
Agriculture	2	0	0	4	0	4	0	1,2	0		0	4
Metals	0	0	0	2	0	4	0	0	0	0	0	2
Energy	1,2	3	3	2,4	0	4	4	1	2	1	1	2
Industry and Services (fertilizer)	4	3	3	1,2	4	4	4	1	2	1	4	1
	2											
	4											
Capital	1,2	3	3	1	0	0	4	1	2	1	1	0
Pollution	2	0	0	2	0	0	4	0	1,2	0	0	0
Labour	1,2	3	3	1,2	0	0	4	1	2	1	1	0
Imports	2	2	2	1	0	0	0	0	0	0	1	0

Coefficient projection methodology

1. Income dependent (cross national regressions of income per capita; the coefficients change with income)
2. Specially projected (expert opinions)
3. Changing with resource depletion (reflecting increasing extraction costs)
4. Held constant

	region-specific		other
	column scaled	0	no entry
	benchmarked		row scaled

The task of building a regionalised model of the world economy was so large that, even with the enormous amount of work that had been done by the authors, it became a tremendous challenge. Thus, the *ad hoc* expert group suggested that other methods for endogenous determination of price changes should be considered, that trade relations should be specified again with a view to incorporating bilateral flows and price elasticities, and that the dynamic properties of the model should be extended beyond the areas of population, trade, and capital formation.

However, no one questioned whether a model with such crude assumptions was able to provide some rough quantitative insights into the nature of world economic interdependence. It was a courageous and ambitious endeavour, a pioneering effort in international modelling, and it was recognised as such by the UN and by the academic community. Because it was essentially an accounting machine with limited behavioural relations, the world model was more transparent than other attempts that used more endogenous 'black box' methodologies, such as system dynamics. Of course, as is typically the case with an input–output type of model, it yields more conservative projections. Also, because a considerable number of exogenous variables and technical coefficients have to be fixed, it leaves most of the responsibilities for the final results of the simulations to the user. The Leontief world model was a stepping-stone for explorers of the long-term future of the world economy. Although it had many limitations, it was nevertheless a source of significant encouragement.

3. Scenarios and results

Because the world model was built at the request of the UN, the scenarios that it explored were essentially relevant to UN issues. For the definition of the basic scenarios, it was essential to cover the elements mentioned in the International Development Strategy (IDS) for the 1970s by exploring longer-term horizons (up to 2000). The scenarios were defined as combinations of exogenous sets of variables and coefficients—that is, *exogenous* both in terms of which variables and coefficients were chosen and in terms of the values used. In total, the report discussed the hypotheses and results of eight scenarios, and analysed in greater depth the basic scenario, called Scenario X.

First, consider the scenario in which the objectives of the IDS are extended up to 2000. Due to higher population growth in developing countries, the income gap is observed to remain stable (that is, the ratio of GDP per capita of developed regions to developing regions would remain 12), as shown in Table 2.

Table 2

Growth rates under assumptions of the IDS minimum targets for developing countries, and extrapolation of long-term growth rates in the developed countries (% rates per annum, 1970–2000)			
		Developed countries	Developing countries
Gross domestic product (GDP)		4.5	6.0
Population		1.0	2.5
Gross product per capita		3.5	3.5
Ratio of average GDP per capita of developed to developing countries	1970	12.0	1
	2000	12.0	1
Source: UN (1976, p. 122)			

Therefore, in establishing Scenario X, changes were introduced both for developed countries (where the average GDP rate of growth 1950–70 of 4.5% slowed down to 4.0% for 1970–2000, and the population growth rate was also slowed down from 1.0% to 0.7%) and in the developing countries (where the GDP growth rate was increased to 7.2% per year). As a result of these changes, the ratio of average GDP per capita of developed countries to developing countries (reflecting the income gap) could be brought down to 7.7 in the pivotal Scenario X. This outcome could be considered a reasonable UN policy target. In an alternative scenario (Scenario C) this ratio could even go down to 7.0—should the GDP growth rate in the developed countries be brought down to 3.6%. Table 3 summarises the key components of Scenario X, the basic scenario for the UN policies.

Table 3

Growth rates and income gap in Scenario X		
Growth rates	Developed countries	Developing countries
Gross product	4.0	7.2
Population	0.7	2.5
Gross product per capita	3.3	4.7
Ratio in the year 2000 of gross product per capita (developing countries = 1)	7.7	1
Source: UN (1979), p. 124		

Needless to say, in Scenario X, the regional growth rates were exogenous. The model was used essentially to compute some consequences of this growth on employment, investment, food production, trade, the balances of payments, pollution, abatement activities, and extraction of minerals and energy. This was the usual way of running the model, and was also the case for scenarios C, D, E, H, R, and M—which incorporated various alternative hypotheses, mainly related to the size of resource endowments and to changes in trade, aid, and capital flow coefficients.

In short:

- Scenario C and D considered alternative population projections (lower in C and higher in D in relation to those in Scenario X), and lower economic growth in the advanced countries;
- Scenario G, H, R and M envisage a situation with food self-sufficiency in Asia; H and R a more optimistic resource endowment; R greater aid and reduced debt services; and M a reduction of import requirements and an increase of export shares of developing countries.

All these alternative scenarios used Scenario X as a reference point.

However, Scenario A was run in an entirely different manner. In this case, the GDP growth rates were endogenously computed, and the exogenous constraints related to the need for (i) full employment in the developed countries and for (ii) the balance of payments to be in equilibrium in the less-developed countries. In this respect, the authors stated that (UN, 1976, p. 115):

> … the future growth of GDP would tend to be determined either by the projected rates of domestic savings supplemented by funds coming from abroad, or by foreign exchange constraints (operating through the balance of payments) which would limit the imports of raw-materials and capital goods that these countries can not yet produce themselves.

The main results for Scenario A are portrayed in Table 4.

Table 4

Growth rates and income gap in Scenario A

(percentage rates per annum, 1970–2000)

Growth rates	Developed countries	Developing countries
Gross product	3.9	5.4
Population	0.7	2.3
Gross product per capita	3.2	3.1
Ratio in the year 2000 of gross product per capita (developing countries = 1)	11.2	1

Source: UN (1976, p. 125).

Scenarios X and A provided the main arguments for discussing the future of the world economy. The essential point made by the authors of the report was that an attempt to reduce the income gap between developed and developing countries would necessarily lead to a substantial increase of the foreign debt of these countries (Scenario X), and that constraining this level of indebtedness would automatically bring down economic growth in developing countries and postpone hopes for reducing the income gap (Scenario A).

As could have been expected from a very large disaggregated model, the actual run of the scenarios provided an extremely large amount of information in relevant areas of interest. Thus, the report (UN, 1976) discussed in detail Scenario X projections for issues such as the changing structure of world manufacturing by regions and sectors, the prospects for food supply and demand, the outlook for grain and animal products, the future for irrigation investments, and the need for fertilisers. The market equilibria for minerals (such as copper, bauxite, and nickel) and hydrocarbons (such as petroleum, natural gas, and coal) were related to costs and levels of resource endowment, and the capital stocks required for resource extraction were computed. Solid wastes, suspended solids in water, particulates in air pollution, and several other pollutants were analysed by considering their long-term developments in terms of emissions and abatements.

All of these issues were matters of great concern for the UN, for many governments and, of course, for those who were devoting their efforts to the World Problematique. That is, it was apparent that there was a complex system of problems to be confronted by humanity in coming decades. But perhaps the most original feature of the Leontief world model was to be found in the area of future trade and capital movements, in which serious—and essentially economic—problems could reasonably be expected to arise in the not-too-distant future.

In Scenario X, world trade (led by trade in manufacturing) was computed to grow at an annual rate of 5.9%, which is well above the GDP world average rate of 4.8%. At constant prices, the share of manufacturing in world trade was expected to jump from 65.4% in 1970 to 86.4% in 2000.

The detailed results showed that two important regions—(i) Latin America medium income (LAM), including Argentina, Brazil, and Mexico; and (ii) Asia low income (ASL), including India, Pakistan, and South-East Asia—could be expected to develop large trade deficits and to face a substantial indebtedness problem under the conditions of Scenario X. Table 5 summarises the findings for these two regions that were close to equilibrium in 1970.

Table 5

International financial flows in Scenario X (billions of US dollars, at current prices)				
	LAM		**ASL**	
	1970	**2000**	**1970**	**2000**
Balance of trade	**–0.4**	**–84.7**	**–4.2**	**–81.7**
Net capital inflows (1)	**0.84**	**13.6**	**9.25**	**4.90**
Net aid flows	**0.88**	**0.80**	**–3.75**	**18.20**
Foreign income or interests (1)	**–1.3**	**–172.7**	**–0.8**	**–128.8**
Balance of payments (1)	**0.0**	**–243**	**0.5**	**–187**

(1) Net capital inflows in these computations include additional capital movements which are necessary to balance the payments deficits. Foreign income or interest payments are calculated on total foreign capital and debt accumulated as a result of such net capital inflows. Balances of payments totals are calculated on the same basis.

***Source: UN (1976, p. 265)*.**

It was therefore rather clear from the exploration made with the world model, that these two key regions of the developing world would be able to grow only with an insufficient level of local savings, and at the expense of a growing level of foreign indebtedness. As already pointed out, Scenario A enforced a balance-of-payments equilibrium with normal levels of capital flows. It was designed specifically to explore this initial conclusion in greater detail. In this case, the model computed endogenously the growth rate of GDP of all regions, the aggregated results of which are shown in Table 4.

Direct comparison of Tables 3 and 4 shows, as might have been expected, that the growth of developed countries was only slightly affected (from 4.0% to 3.9%) by the changing set of hypotheses. The developing countries, however, saw their GDP growth rates reduced from 7.2% in Scenario X to 5.4% in Scenario A. As a consequence, the income gap remained practically constant, as reflected in the GDP per capita ratio of developed countries to developing countries—which was computed as 11.2 in 2000 and 12.0 in 1970. Bringing per capita income in developing countries closer to the world average would not come by itself. Rather, massive capital transfers would be required. A UN report could not openly spell out such a conclusion—but the model was there, showing the evidence.

4. Looking backwards from 2000

Since the early 1970s, the world economy has slowed down, and population growth has been lower than expected. Table 6 summarises the most recent estimates for the period, in a form directly comparable to Table 3 (Scenario X) and Table 4 (Scenario A).

Table 6

Observed growth rates and income gaps, 1970–2000		
	Developed countries	Developing countries
Growth rates		
Gross product	2.5	4.1
Population	0.5	2.2
Gross product per capita (1987 prices)	2.0	1.9
Ratio of GDP per capita in 2000		
In US dollars at 1987 constant exchange rates	12.3	1
In US dollars at current exchange rates	14.7	1
At PPA rates	5.4	1
Source: Own estimates, UNDP, data banks.		

Inspection of this table shows that the growth rates of the International Development Strategy (IDS) were quite different from the actual future course of events, for both developed and developing countries, for reasons that are tentatively explained below. But probably the most interesting observation lies in the fact that the main objective of reducing the income gap—that is, lowering the ratio of GDP per capita between developed and developing countries—has not been met, and the ratio remains very close to the initial level of 12.0. This result points to the fact that the world has been moving more in a Scenario A configuration, than in a Scenario X fashion of fast development of international cooperation.

Scenario X was normative: it corresponded to the objectives put forward by the UN, that never were met. Scenario A simulated a situation in which constraints would set limits to the deficits in current account balances of developing countries, much in line with what the IMF would term as “structural adjustment policies” of the last decade of the twentieth century.

It should be noted that the gap can also be measured at current exchange rates, in which case the ratio for 2000 would be higher than the initial 1970 ratio. Obviously, it can also be measured at PPP (Purchasing Power Parity) rates, in which case the welfare value of developing countries income is considerably increased. However, the PPP measure is not relevant for a comparison with the initial current US$ exchange rate measures used in the report, neither for 1970 nor for the target years.

It was impossible for the scenario writers in the mid 1970s, coming as they did from an historically unique period of continuous strong growth, to imagine such a sizeable slow-down. Even allowing for the 'oil shock' and the dismantling of the Bretton Woods financial stability system signalling some dangers ahead, it was difficult for scenario writers in the 1970s to extract credible indications of long-term structural changes from such short-term events.

It was only later that Freeman (1984) was in a position to provide a convincing explanation of what had happened at the time that the Leontief world model had been built. In commenting on the MIT models (Forrester, 1971; Meadows, Randers & Behren, 1972), Freeman (1984, p. 499) had this to say:

> The characteristics of the MIT models are those of the *fourth Kondratiev* upswing- a techno-economic paradigm based on cheap oil universally available as the foundation for energy-intensive, mass and flow production of standardized homogeneous commodities such as consumer durables, and the associated capital goods, components and services.
>
> This techno-economic paradigm permitted the massive expansion of the world economy during and after World War II, following its successful development in the US automobile industry in the previous three decades and during the war itself. Although it enabled very big productivity increases in many branches of manufacturing and in agriculture, and an enormous associated proliferation of public and private service employment, it ultimately began to encounter *limits* to further growth in the late 1960s and 1970s. This was not *just*, or even *mainly*, a question of the oil price increases, but of a combination of factors including the exhaustion of economies of scale, diminishing returns to further technical advance along existing trajectories (Wolf's Law), market saturation factors, pressures on input prices, declining capital productivity and the erosion of profit margins arising from all these factors, as well as the culmination of the competitive pressures from the Schumpeterian *swarming* process.

These comments on the MIT models also apply to the model of Mesarovic and Pestel (1974), as well as to the Leontief world model.

At the end of the 1980s, there was a general move towards free trade and market economies, and towards greater regional integration. No past trends were able to explain this radical transformation, although an analysis of such types of events had been carried out on the basis of subjective *a priori* probabilities (Fontela & Gabus, 1974).

The present is not what the future used to be, and it is useful to build long-term models—even if only to help us understand, *a posteriori*, the reasons for change. As T.S. Eliot noted with such great eloquence: "We shall not cease from exploration, And the end of all our exploring will be to arrive where we started, And know the place for the first time".

From a strictly technical point of view, all of the world models built in the early 1970s probably shared the same difficulty in exploring the future—a failure to depict the processes of change brought about by introducing prices and technologies into the picture. Prices reflect scarcities, and their evolution induces technological change. In turn, technology changes costs and prices. Such are the Schumpeterian dynamics that determine the problem of "limits".

Of all the models built at the time, the Leontief model was the only one that, in principle, allowed for the introduction of this price–technology dynamic—using price-sensitive equations for demand and for technical coefficients. That said, in the version of the model that was left to us by Carter, Leontief, and Petri, these elasticities were not even specified. They relied on an exogenous treatment with very simple and conventional assumptions. But the accounting system was open to these developments of the model. Unfortunately, circumstances never allowed for these developments to take place at later stages of the modelling exercise.

5. A tentative research agenda

Exploring the future should never be identified with forecasting. Whereas forecasting is founded on determinism, futures research encompasses a view of the world based on freedom of choice. Leontief's world model has been one of the most ambitious methodologies ever attempted to explore the long-term future of an infinitely complex system subject to continuous deep structural changes.

The exercise was successful, among other things, in pinpointing the balance-of-payments constraints in developing countries, and in identifying signals of what was later to become the debt crisis. It helped to coordinate the policies of the many agencies of the UNO, and most probably played an educational role for those involved in decision-making affecting the future of the world, both inside and outside the UNO. Needless to say, Leontief was courageous enough to extend the 'cooking recipe' beyond its traditional boundaries. As a consequence, he met enormous methodological and data problems, and risked severe criticism from the conventional academic community. But the final output was outstanding—thanks to Peter Petri and Anne Carter who, with rudimentary data and little computer capacity, devoted extraordinary effort to an extraordinary endeavour, and to Faye Duchin who has extended work with the model in more recent times.

Should research along these lines be continued? Of course, the answer should be 'yes'. The data have continuously improved, and a single statistical observation system for all countries of the world—the 1993 UN System of National Accounts (SNA) and the System of Environmental Accounts (SEA)—provides promise that some of the severe hypotheses used for data preparation in the world model, could soon be withdrawn. The number of countries officially publishing input–output tables, or making and using matrices linking commodities and industries, has increased. The crude income regressions for technical or consumption coefficients could now be replaced by appropriate time series models in many regions. Furthermore, the development of Social Accounting Matrices (SAMs) offers a possibility for more complete descriptions of the regional subsystems.

Modelling has also developed new tools that could be incorporated in a world model. The private consumption coefficients might be derived from behavioural equations (allowing for price and income elasticities and utility maximisation), and the determination of the future technical coefficients of the input–output tables might also incorporate more explicit technology and price-sensitive models. Experiments performed with general equilibrium models, under neoclassical assumptions, already point to the fact that a new world model could be considerably more closed, with more endogenous determination of variables.

Moreover, the concept of 'scenario' has also evolved towards a more comprehensive understanding of overall economic, social, and political variables, and new forms of linkages between broadly defined scenarios and world models can now be envisaged. Methodologies of futures research, such as cross-impact analysis (Helmer, 1972) or interpretive structural modelling (Warfield, 1976) could considerably improve the simulation aspects of world modelling (Fontela, 2000).

In a world in which the market economy extends to cover the entire globe, in which the new technologies of the Information Society induce a new long-term upswing for the world economy, and in which new unexpected events challenge these expectations, it is apparent that futures research in the area of world modelling, with quantitative interdependent models, is again urgent and necessary. This is a key challenge for the input–output research community, and provides a full research agenda for the years to come. This imperative is, in part, a legacy of the work of Wassily Leontief.

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