WORKING PAPER

THE USE OF AGGREGATED ECONOMETRIC INPUT–OUTPUT MODELS FOR MACROECONOMIC IMPACT ANALYSIS OF CIM TECHNOLOGIES

A Comparative Study of Existing Approaches with Conclusions for Further Research at IIASA

Jens Kammerath

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FOREWORD

This paper presents work done during the summer of 1988 by a member of the Young Scientists Summer Program (YSSP) at IIASA. It is of special interest to those involved in the CIM project, and its collaborators.

Professor Robert U. Ayres	Professor Dr. F. Schmidt-Bleek
Project Leader	Leader
Computer Integrated Manufacturing	Technology, Economy & Society Program

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1. Introduction

This paper is devoted to the issues of macroeconomic impacts of Computer Integrated Manufacturing technologies 1). The Analysis of new technologies in the context of economic growth and structural change of national economies is an important aspect of systems analysis of innovation processes. Beyond direct economic impacts new technologies cause a variety of induced effects due to the interrelations between the economic system and the production activities immediately affected by these technologies.

Analyzing macroeconomic impacts of CIM technologies, we can rely on a considerable stock of scientific and practical results and on a variety of proved tools both for research and decision support purposes. It will be useful to describe here this practical and theoretical background of the analysis in brief.

In the field of practical experience at least the following three 'roots' of further research are worth mentioning:

1) <u>previous studies on macroeconomic impacts of CIM and related technologies, using input-output techniques and econometric models</u>, as, for instance, the results of Fleissner et al. [1981], Leontief/Duchin [1986], Howell [1985], Ayres/Brautzsch/Mori [1987] and the promising study of Kinoshita/Yamada [1988]. Ayres et al. [1987] compared some of these studies, pointed out general methodological problems and drew some conclusions. To a certain extent this work will be carried on in the present paper.

2) the <u>experience of the IIASA CIM project</u> concerning analysis and forecasts of CIM technology diffusion and the analysis of CIM implementation issues on the firm level. For these purposes within the CIM project previously have been used, first of all, logistic diffusion models, the production function apparatus, and a technology penetration model linking macro and micro level 2).

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1) This term is treated here in a broader sense, i.e. including not only fully integrated manufacturing systems, but also stand-alone applications of the main components of CIM, such as numerically controlled machine tools (NC-machines), industrial robots, flexible manufacturing systems and computer-aided design and manufacturing (CAD/CAM) systems. We will look at the structure of this complex of technologies below.

2) Yet without considering interindustry linkages, in principle relying on composition of micro to macro behavior. see Tani [1988]

Calculations were performed for industrial robots and NC-machines on Japanese, US and CSSR data. A worldwide data base on flexible manufacturing systems (FMS) has been collected and analyzed from the viewpoint of cost/benefit performance, social and managerial issues. This work is going on now on the base of detailed FMS questionnaires.

All these studies, together with related research results in other institutions in different countries, will provide a more or less comprehensive description of the diffusion process of CIM technologies. Probably this is the most important prerequisite for a sufficiently reliable macroeconomic impact analysis.

3) The 'multinational' experience in using economic models for macroeconomic analysis. This paper is focusing, above all, on econometric input-output models, because they allow to trace the causal chains of macroeconomic impacts both in terms of interindustry relationships and of interdependences between economic variables describing economic behavior and basic balance equations. Compared to 'pure' input-output, the econometric extension of these models helps to overcome some of their disadvantages, connected with the relative rigidity and onesidedness of the concept.

Yet there is an overwhelming variety of those models in the world. It is rather difficult to estimate the comparative advantages and disadvantages of the different model structures. There are also several approaches to integrate econometrics into an input-output framework or vice versa. The development of the IIASA-INFORUM family of econometric input-output models and the dissemination of the G and SLIMFORP special software packages by IIASA were important contributions to this field of research. (see Input-Output [1981-1985]).

In any case, for the purposes considered here, the model structure must be specified according to some concept of possible paths of the macroeconomic impact of CIM. That does not mean, that the model is to be built 'from scratch'. Most of the studies quoted under (1) have been performed on well-proved models, frequently used for other purposes already before.

However, pure extrapolation of previous practical experience might with time lead to a certain 'research bias', if not regularly confronted with the underlying theoretical concepts. Main pillars of the theoretical background of our research subject should be considered innovation theory, systems analysis, and structural dynamics.

These terms may not be precisely comparable regarding their level of abstraction, and there may be overlappings. But each of them represents a way of thinking, which can express some essential side of the macroeconomic influences of innovation processes such as CIM technology diffusion.

Again the main ideas shall be described in brief:

1) Innovation theory substantially improved our knowledge about inner laws of technological development. Two aspects of the characteristic way of thinking of this theory are especially important for macroeconomic impact analysis: the time performance of technological development and the concept of technological interdependences between industries.

   The first aspect includes the concepts of product and technology life cycle and dynamic efficiency as well as long-term aggregate time behavior of innovations, of basic technological indicators and of the economy as a whole, appearing in the form of 'long waves', medium-term and short-term cycles.

   The second aspect mainly is connected with linkages between innovation processes in different industries, the driving forces, economic mechanisms and diffusion paths of new technologies. Thus initial and induced innovations, motive, career, and induced branches are considered (see, for example, Perez, [1984], pp. 62-63). A similar concept was applied by Ranta [1988] to the case of CIM technologies (see pp. 5-7).

   A certain synthesis of these two aspects is expressed by the terms of 'technological paradigm' (Dosi, [1984], p. 14-15) and 'technological style' (Perez, op.cit., p. 59). Thus innovation theory provides the theoretical background for the diffusion analysis of any particular new technology. On the other hand, it allows to locate both in space and in time this particular innovation process within the framework of interrelated innovations of the present technological transformation.

2) Systems analysis is mentioned here, because its characteristic interdisciplinary, complex, dynamic and 'unprejudiced' systems approach is likely to avoid biased conclusions, caused by the restriction of the research to a particular subject - macroeconomic impacts of CIM, and to a particular class of tools - econometric input-output models.

   Of course, these restrictions themselves cannot be completely eliminated. But in any case it is necessary to be aware of these limitations both of the subject and the tools. Otherwise essential feedbacks mediated by relationships not under consideration could be disregarded.

   In the case of CIM technologies especially social impacts in a broader sense are worth mentioning here. New technologies in the long-run deeply will affect style and quality of life, institutional and organizational patterns of society. Modern forms of manufacturing automation change contents of work. New qualification structures and even education strategies are desired 1). Extended leisure time causes demand in new kinds of consumer goods and services, in new forms of social communication. Finally, new technologies must improve the relationship between man and nature 2).

Different types of organization of society will prove their advantages not only in the field of creation of new technologies, but by the manner they cope with these social impacts in order to transform technical into social progress as well.

3) Structural dynamics denotes a particular concept in economic analysis, which is concerned with the influence of technological change on the industry structure of the economy and, in particular, of employment. The studies on these issues can be traced back, e.g., to the analysis of the impact of machinery on level and structure of employment by Marx 3). A remarkable example for new contributions to this field of research is the work of Pasinetti 4).

Structural dynamics can justly be considered the connecting chain link between innovation theory and structural analysis with the help of economic models subdivided by industries. For these models are used in economic theory (as, for instance, by Pasinetti), this link helps to bridge a certain gap between innovation theory and structural analysis as two rather different ways of looking at economic systems.

So far as these models are also tools for practical calculations and for decision support, this link connects different levels of abstraction. It provides the theoretical background for measuring technological change in terms of economic models reflecting industry structure. By the way, Dosi refers to this connection between two important fields of research, too 5).

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1) Some of these aspects have been analyzed, e.g., in Leontief [1986] and Fleissner et al., [1981].

2) This issue to a certain extent can well be reflected even in input-output models. See, e.g. the three articles on environment impact analysis (1970, 1972, 1973) in Leontief, [1986].

3) see, e.g., Marx, [1867], chapter XV, section 3, 6, and, in particular, section 7 - 'Repulsion and Attraction of Workpeople by the Factory System. Crises in Cotton Trade.' (pp. 421-432)

4) Pasinetti, [1981]. see, first of all, Chapter X - 'The Structural Dynamics of a Growing Economic System', pp. 219-244

5) op.cit., p.296: 'In many respects, our work ends where Pasinetti's (1981) begins. Although it is by no means

So far as economic models are efficient tools for economic policy formation, they can substantially contribute to the transmission of these important theoretical findings into economic practice.

There is an obvious need for systems analysis and impact studies of new technologies on the national level in all industrialized countries. Nowadays we are facing an <u>increasing role of government science and technology policy</u> both in market and centrally planned economies.

Beyond the practical and theoretical background of the analysis, this is another essential starting point for economic modeling of macroeconomic impacts of CIM. For the design of a model it is important, whether the model is to be used in economic theory or for policy formation.

In this connection it is useful to distinguish the following 'application modes' of economic models:

1) Application in <u>economic theory</u> is focused on qualitative relationships. Calculations are often performed on analytic expressions rather than actual data. The latter are used, above all, for illustrative purposes.

2) Application in <u>'applied branches'</u> of economics up to dedicated applications for decison support in some <u>'advisory mode'</u>, e.g., in the field of government policy formation.

   In such an 'advisory mode' the model itself is run by the model-designers after they have 'translated' the subject of analysis or some particular decision problem into the terms of the model.

3) Implementation of economic models within the framework of <u>interactive decision support systems</u>. While in an 'advisory mode' model-users fully depend on model-designers, in this case, for instance, policy makers or officials in government institutions could analyze different scenarios of government policy in a certain field without permanent assistance of model-designers.

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easy to link our discussion with Pasinetti's model, we can say that the latter provides the "macro-co-ordinates" in which the process of technical change takes place, and the conditions of dynamic equilibrium which fulfil its dual nature in terms of changing demand and changing conditions of production: our analysis has aimed to discover what actually happens in each sector, while Pasinetti's model concerns what must happen at macroeconomic level owing to the patterns of interdependence between sectors and to the trends of income distribution.'

In the last two cases special requirements must be met by the models:

A) The set of endogenous and exogenous variables and the degrees of freedom of the model must reflect the actual decison making problem or decison situation. Fixed preconditions and the scope of the decision in terms of the actual control variables must be taken into account 1).

An interactive decision support system, in particular, has to reflect the decision procedure, too.

B) So far as there is a certain division of labor between model-designers and model-users, to the latter should be transmitted not only 'pure' results, but also the knowledge of underlying assumptions and limitations of the model.

In most of the cases it is very difficult to specify the influence of model assumptions on the solution. That's why together with efficient methods of model handling reliable verification tools must be provided, which enable economists and decision makers to evaluate model outputs without losing themselves in 'pure technical details'.

From this some conclusions for macroeconomic impact analysis of CIM technology diffusion should be drawn.

First, while aiming to support policy formation in this field, the potential user of the model as well as the actual decision problems have to be specified. Obviously, the present form of economic organization of the country(ies) under consideration is a strong determinant in this respect.

Secondly, any finding of macroeconomic impact analysis must be considered in the context of possible responses of government policy.

So expected trends in employment, level and structure of qualification, and contents of labor should be met by appropriate strategies and structures of education, reeducation and supporting social policy measures. Conclusions for investment allocation or, say, assignment of subsidies, should be derived from the well-known multiplier effects.

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1) L. Johansen introduced the term of 'operationality' to denote this kind of characteristics of economic plans and economic models for supporting their elaboration (Johansen [1978]).

Thirdly, one should not expect unconditional acceptance of the results by the decision makers. Responsibility for decisions is incompatible with inscrutability of means of decision. That's why user-friendly verification tools as mentioned above are needed even in the case of conventional, seemingly simple methods like input-output analysis. We will return to this question below.

The following analysis will start with the concept of networks of causal chains. Afterwards possibilities of analyzing causal paths of macroeconomic impacts of CIM technologies will be demonstrated. Then an aggregated econometric input-output model of the US economoy and the product chain analysis software will be described in brief as examples of tools for the analysis of these issues.

2. Economic Models and Networks of Causal Chains

An economic model is the reflection or description of the causal relationships between the inputs, the state and the outputs of an economic system. According to the forms and the methods of this description we distinguish different types of such models.

The main purpose of the often real 'Sizyphus' work of model design and data collection is to provide means for the analysis of possible impacts of input (or control variable) changes on system behavior - first of all on its outputs. Thus the idea is to obtain optimal control strategies to gain desirable or sustainable system outputs.

This rather simplified outline of economic modeling, nevertheless, provokes some serious questions: How to describe both quantitatively and qualitatively determined causal relationships ? How to ensure all important causal interconnections with considerable influence on systems behavior are included ? How to define 'desirable' or 'sustainable' outputs ? Can we really trust a model, which in any case provides an abstract, simplified idea of real life ? How to reflect within the model not only the control strategy but the 'control philosophy' as well, i.e. the choice of the set of control variables rather than their actual values ?

The sequence of questions could well be continued here. Some of them will be reconsidered below. In the introduction there was already stated that the studies reported in this paper mainly dealt with econometric input-output models. Till now, no reason has been given for this choice.

Actually, what kind of economic models could be used for the analysis of macroeconomic impacts of CIM technologies ?

First of all one could consider a more descriptive, 'black box' approach, analyzing, e.g., the correlation between aggregated dynamics of a national economy and some indicators of CIM technology diffusion and their dynamic efficiency. This is an tempting direction because of its relative simplicity - aggregated econometric models exist in most countries and even for linked national economies up to world models.

Yet there is one great disadvantage. These models only to a very limited extent allow to trace causal chains from technology diffusion to macroeconomic impacts. They indicate some aggregate linkage, which at least in part may be fictitious, even if statistically significant. This problem may be worsen if the new technology under consideration constitutes only a very small part of the national economy 1).

Thus a kind of model is desired, which <u>reflects the production processes affected by these new technologies</u> as a well-defined 2) subsystem of the national economy and at the same time allows to <u>trace causal chains to macroeconomic behavior</u> (including feedbacks).

This model will not be a 'black box' but specify the network of relevant causal chains in an explicit form. Giving the possibility to attribute changes in aggregate behavior to 'elementary' causal chains, the model simultaneously will provide the base for the verification tools mentioned above.

To a great extent the results of the impact analysis are influenced by the network of causal chains explicitly represented in the model. The model should contain all relevant causal chains affected by the new technologies. That is, the <u>measurement of influence is based on the underlying concepts of influence</u>.

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1) Ayres/Brautzsch/Mori also referred to this problem: 'The effects on the sectoral and on the macroeconomic level can be so low in some cases, that they would lie within the error margin of the parameter estimation of the input-output model' [1987, pp.4-5].
Thus the share of the metalworking machinery and equipment industry in gross output of the U.S. economy in 1981 came merely to 0.38%, in GNP - to 0.42%, and the contribution of the commodity group of the same name to gross private fixed investment - to 2.79% (see industry No. 47 in U.S. Input-Output, [1987]).
By the way, 1981 was not the worst year for this industry. On the other hand, NC machine tools, for instance, are only a part of this industry's output.

2) well-identified in terms of the interconnections of the subsystem with the entire system.

Therefor a thorough systems analysis of the CIM technologies is desired not only for scenario design but also for model selection.

Here some words about the concept of causality are in place. This concept seems to be too restricted in many cases because of its unidirectionality. Yet in real life most of relations between things, phenomena, processes or concepts are interdependences , interrelations with cause and effect changing their places and not absolutely attributable to one of the sides of the relationship.

So in economic models a so-called 'independent' variable often can well be replaced by another one, simply transforming the expression and bringing out the new variable to the left side instead of the old one 1).

But causality in its philosophical sense does not include unidirectionality, and mathematical models allow for interdependences by introducing feedback loops between variables as well. The reflection of steady states, equilibrium or disequilibrium in economic models is based on these feedbacks and loops. In any case, one should be aware, that seemingly unidirectional relations in models might be a simplified reflection of complicated interdependences in reality.

Another issue connected with causality in economic models is that of spurious correlation. Often it is caused by similarities in time trends of economic variables, which are not really interrelated directly. Like in the case of unidirectionality, only thorough economic analysis can prevent oversimplifications and incorrect conclusions.

Dealing with networks of causal chains in economic models it is necessary to distinguish at least three levels of analysis:

A) the network of flows, i.e. interindustry flows of materials, flows of capital and consumer goods;

B) the network of measurable causal relationships between economic variables;

C) the conceptual network of qualitative causal relationships, e.g., between initial and induced innovations in different industries (in other terms - the network of diffusion paths) or the causal chains of social impacts in a broader sense, including, e.g., consequences for education concepts and leisure time behavior.

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1) Indeed, such formal transformations do not reflect in every case the actual possibility of redirecting underlying causal relations. Often they can be considered rather a 'mental' redirection in order to recognize necessary conditions for gaining a desirable effect.

The first, the network of material flows and flows of goods, immediately shows the linkages between different stages of the productions processes as they are determined by the technologies actually in use and the intensity of different production activities. As far as , e.g., an increase in the production of some good will cause an increasing demand for components, raw materials etc. along the production chains, terms of causality can be applied here.

Again this is not a rigid, inflexible kind of causal determination, because there is, e.g., a variety of possible responses to increasing demand for components or raw materials - from increasing domestic production or imports up to redistribution of shipments between purchasers.

The second one, the network of measurable causal relationships between economic variables, is a quantitative reflection of causal relationships of the underlying economic system. While the first network gives only a more or less static picture, a 'photography' of the real side of the system, the network of interrelations between variables explicitly deals with changes in economic performance and behavior. At this level of analysis besides the real side, the material processes, complex economic interdependences are involved.

Material flows are results of the functioning of the relationships described on the second level. At the same time, technological interrelations are mediating most of these economic inerdependences between industries.

The conceptual network of causal relationships describes causality in qualitative terms and thereby includes also non-quantifiable terms and relationships. This kind of network must be attributed to higher levels of abstraction in the cognitive process.

These three levels of abstraction are closely interconnected in the cognitive process, and so are the underlying relationships in the real economic systems.

For all of these networks appropriate formal tools both for economic research and decision support are available. The classical tool for the first level is the input-output table, just reflecting flows of materials and goods between industries, but not explicitly describing causal interdependences neither between performance of different industries nor between different economic variables.

In terms of input-output tables this can be done with the help of input-output models, which, however, must be attributed to the second level of analysis or some intermediate one. Typical tools of the second level are, besides the already mentioned input-output models, econometric models and system dynamics models.

Though at first sight it might seem not very useful to try to formalize interdependences also on the third level, some approaches have already been proposed. One of them is connected with the concept of 'cognitive maps' 1).

It was developed as a tool for the analysis of policy decision processes. The main idea is to reflect the network of qualitative causal beliefs of decision makers in a formal way, so that it becomes possible to perform certain calculations and simulations in order to predict, e.g., a persons reaction to several events.

Later this method was used by other authors for the description of the causal structure of a system rather than cognitive structures of persons 2).

Similar concepts, among other ones, are used in modern Artifical Intelligence (AI) approaches. Thus, e.g., Knowledge Engeneering is concerned with the formalization of subjective knowledge in the form of 'rules' to include them in a 'rule base' on a computer. Causality is one possible type of those rules. After they have been stored, they can be used for further processing 3).

Here, like in the case of cognitive maps, formal methods and computer facilities are used to cope with the complexity of causal structures, including both quantifiable and non-quantifiable relationships.

Economic models can be attributed first of all to the second level of analysis. To a certain extent they can be considered a synthesis of the theoretical concepts on the third level and the descriptive data on the first.

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1) see Axelrod [1976]

2) see, for instance, Kishi et al. [1986]. In this article cognitive maps are used in the context of system dynamics.

3) The process of obtaining cognitive maps by 'documentary coding methods' or 'questionnaire methods' described by the authors of this concept can be considered some kind of knowledge engeneering, too (Axelrod [1976], App. 1,2)

3. CIM Technologies from the Viewpoint of Input-Output Models

For macroeconomic impact analysis of computer integrated manufacturing technologies with the help of economic models we have to start with the description of these technologies in terms of these models.

First a sector classification must be choosen. On the base of this classification it must be possible to reflect the inputs and outputs, the costs and the benefits of the new technologies as well as the main relationships of the economy as a whole. On the other hand the sector classification is predetermined by the existing data base on the technology diffusion and on the national economy.

The solution of this contradiction can only be some compromise. Modeling the national economy requires a certain level of aggregation. Selected technologies like CIM, robots, NC machines and CAD/CAM can be measured and analyzed only on a relatively detailed level.

If one decides for the connection of a detailed representation of the new technologies with an aggregated model of the economy, the main task to be solved will be the linkage between these two parts of the model.

It is rather difficult, for instance, to identify the material flows caused by a specific technology within an aggregated industry classification. Due to the aggregation level, a part of them will even appear as inner flows of some industry.

Another part will not appear at all in an I-O table because of some components might not be sold to other companies but will be consumed by the same company that produced them. Thus division of labor within and between companies will affect interindustry shipments as shown in the input-output tables.

This problem becomes obvious if looking, e.g., at the U.S. input-output table for 1981.

Fig.1 gives some idea about the structure of the complex of CIM technologies. In the right part of the picture the technologies belonging to this complex and the linkages between them are represented (see footnote (1), p. 1 of this paper).

Industrial robots and numerically controlled machines are used both in stand-alone applications and in flexible manufacturing or computer integrated manufacturing systems. Sheinin/Tchijov [1987, pp.14/15] analyzed the number of robots and NC-machines included in FMS using the world-wide FMS database of the IIASA CIM project. Lakso [1988] studied the influence of FMS technology on the efficiency of NC-machines included in these systems. So in principle it is possible to describe these linkages also in a quantitative form.

Computer Aided Manufacturing (CAM) usually is an integrated part of all FMS and CIM applications. Yet until now the immediate linkage between Computer Aided Design (CAD) and CAM - the often stressed CAD/CAM didn't become the typical case.

On the left hand side of the figure some important innovative components of these technologies are shown. For the analysis of CIM technologies with the help of input-output models these components must be attributed to the appropriate sectors of the sector classification of the I-O model and to certain interindustry material flows represented in the I-O table.

New materials are required, above all, both for semiconductor industry and for more reliable and precise tools as needed for computer-controlled machine tools with integration of different functions and automatic tool and workpiece changing. Modern control equipment, in-process gauging systems, servo-motors and laser systems (for gauging and orientation, e.g., of automatic guided vehicles - AGV) are also important new components desired for these technologies.

There is a class of components needed especially for FMS and more sophisticated CIM systems, which probably will change the input structure of FMS producers substantially - automatic guided vehicles, automatic pallet and tool changers and automatic storage and retrieval systems.

Finally, modern communication technologies play a key role in the integration process of CIM systems. Office automation is included in this process, so that there will be an efficient linkage, e.g., between production planning and process control. This will lead to higher software requirements. So far as software is bought from other companies, this will affect interindustry flows of services 1).

FMS and CIM will utilize their potential efficiency only if all manufacturing organization is modernized basically. New logistic technologies such as Kanban or just-in-time are mentioned here, because they will make the manufacturing flexibility of FMS and CIM a flexibility for the customers of the firm.

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1) This is one of the most serious problems for impact analysis. It is very difficult to determine, for instance, which amount of desired software is produced by FMS system vendors, by FMS users or by specialized software firms.

Fig. 1 - Selected Important Components of CIM Technologies.

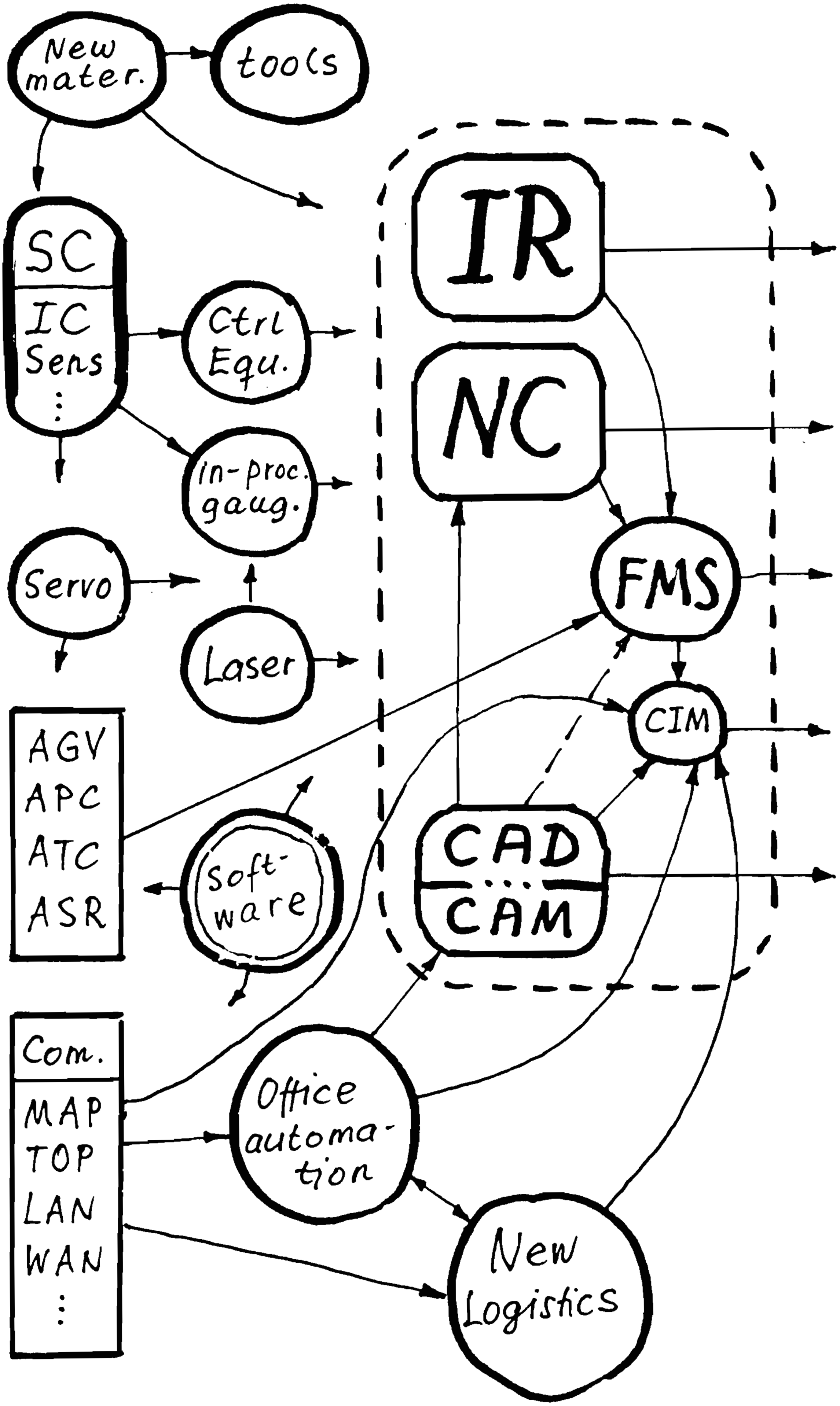

Figure 2 shows the main backward linkages of the commodity group 'metalworking machinery and equipment' of the 85-sector U.S. input-output table for 1981 , which in particular includes machine tools, among them NC-machines 1). For figure 2 and 3 a personal computer program called 'Product Chain Analysis' was used. It has been developed at the Economic Research Institute of the State Planning Commission in Berlin/GDR. The theoretical background and the facilities of the program are described in the appendix to this paper.

The relationships in fig. 2 look much more prosaic than the variety of key components of CIM technologies as shown in fig. 1. The box on the right represents domestic output for final consumption of the commodity No. 47 in millions of 1981 dollars. Starting from this commodity, the product chain 'Metalworking Machinery and Equipment —> Electrical Equipment —> Electronic Components —> Nonferrous Metals' is listed.

Every column of the figure represents a certain stage of the production process in terms of the 85-sectoral commodity classification of the U.S. I-O table. The products belonging to the considered chain are listed in double-line boxes. For every stage together with the chain commodity main components also consumed in the same process are shown.

Now, as mentioned above, it is necessary to attribute different components of CIM to the sectors of this model and to the flows between them. So electronic industrial control equipment has to be searched for in the 'Electrical Equipment' commodity group, semiconductor components - in the 'Electronic Components' group.

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1) The input-output data for 1981 were published in U.S. Input-Output [1987] as two tables - the Use and the Make table, showing the consumption of different commodities by each industry resp. the output of different commodities by each industry.
For product chain analysis they have been transformed from this commodity/industry form to the commodity/commodity form, using the method described in U.S. Input-Output [1984a]. This was necessary to obtain technological relationships instead of shipments between industries. The BEA method is based on the contested industry technology assumption, but it is relatively simple and does not produce negative elements.
Since data were available only on the 85-sector level, all calculations were performed on this level. So in comparison with the published BEA commodity/commodity total requirement tables differences may appear.

Fig. 2/3 - Product Chain Analysis for Commodity No.47 - Metalworking Machinery and Equipment, based on U.S. Input-Output Data for 1981

Fig. 2 - Backward Analysis

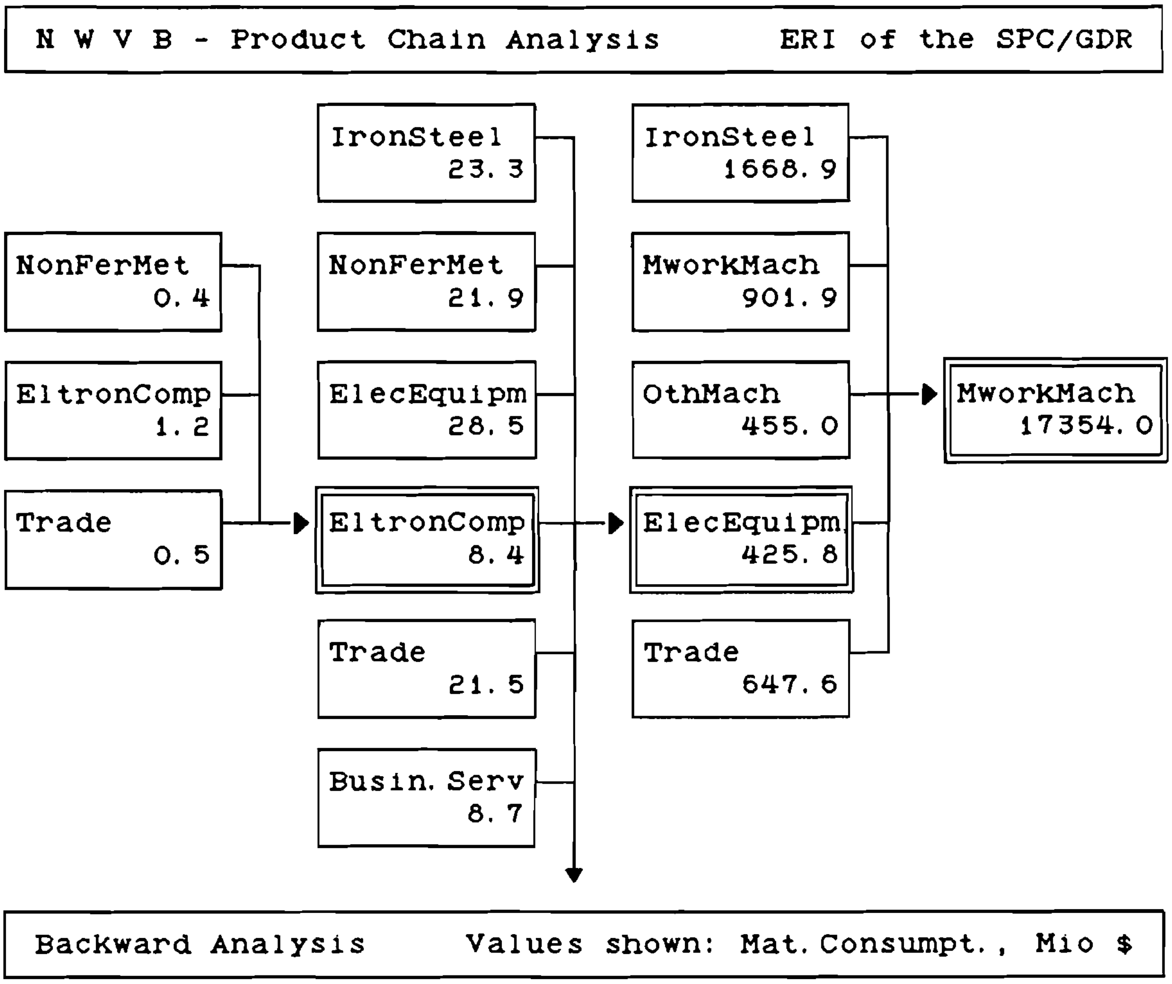
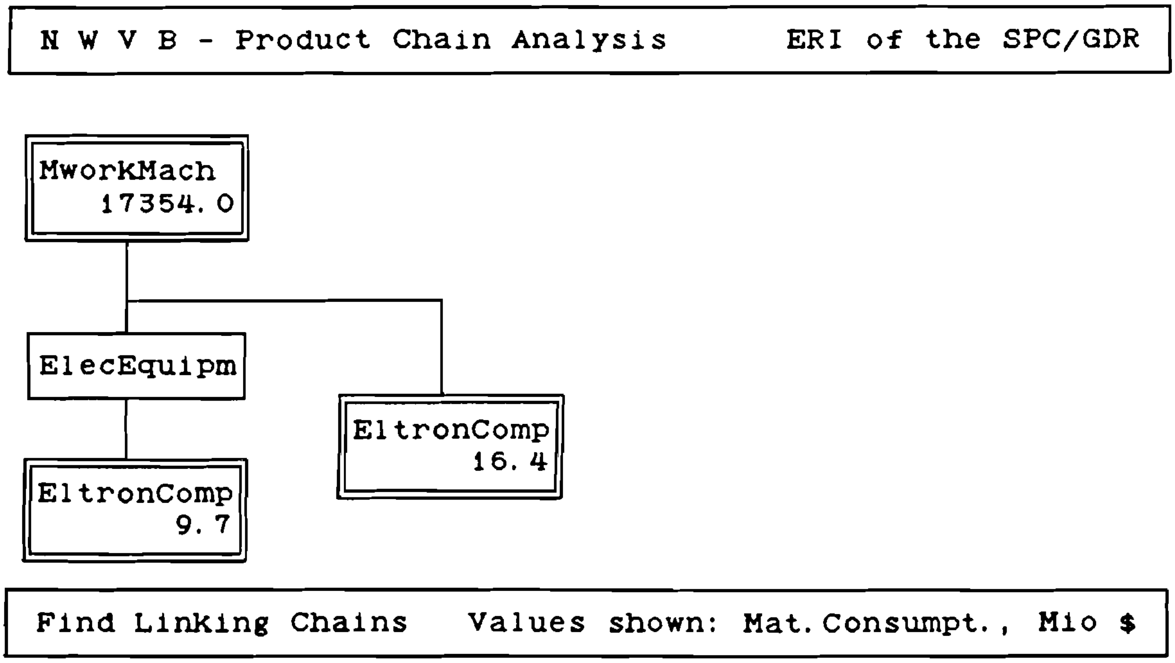


Fig. 3 - Analysis of Linking Chains



Software bought by the CIM technology users from other companies and not included in the system costs, e.g., of a FMS, appears in the sector 'Business Services'.

Fig. 3 demonstrates another feature of Product Chain Analysis. It is possible to search within the direct material requirement coefficient matrix for all relevant product chains linking two commodities. If a sufficiently small tolerance value was used for the search, the sum of all these chains will accord with the corresponding total requirement coefficient (see the Appendix A to this paper).

<u>How did the inputs of industry No. 47 change over recent ten years</u> ? In table 1 the most important inputs (commodities) of this industry for the 1972, 1977 and 1981 I-O tables are compared. This comparison is based on the original 'Use'-tables (i.e. commodities, used by industries) as published in the Survey of Current Business to avoid distortions due to the transformation algorithm.

Table 1 - Changes in Input Composition for Industry No.47
'Metalworking Machinery and Equipment'

Mln.curr.$	1972		1977		1981
Total Output	7155		13157		22240
Value added	4301		7820		12953
Intermediate Input	2854		5337		9287
Value added/Output	60,1%		59,4%		58,2%
Interm.Inp./Output	39,9%		40,6%		41,8%
Input position	Flow	UMS	Flow	UMS	Flow
31. Petrol refining	50	-13	79	86	220
36. Stone/clay	58	20	127	0	215
37. Primary iron/steel	653	-20	1181	-45	1951
38. Prim. nonferrous	169	-10	301	-86	423
47. Metalworking M/E	409	-46	706	15	1208
49. General Ind. M/E	158	-19	272	23	483
50. Miscell. Machinery	172	-13	303	89	601
53. Electr.Ind.Equipm.	178	29	356	-25	577
65. Transp./Warehouse	58	28	135	2	230
69. Wholesale/Trade	181	82	415	105	806
73. Business services	152	-7	273	18	479
Sum of selected posit.:		33		181	
Sum of Intermed. Input:		89		266	

UMS: Unit material consumption saving/increase
("-": saving "+": increase)
M/E: Machinery and Equipment

Source: Use tables in U.S. Input-Output [1979,1984,1987].

In the upper part of the table total output and the global cost structure of industry No. 47 are listed. One can observe an increasing share of intermediate input in total output. The data for different kinds of materials give a certain idea about possible causes for these cost dynamics. Together with the flows 'unit material consumption saving' was calculated by the following formula:

$$UMS = Flow(year2) - Flow(year1) * \frac{Tot.Outp.Ind.47(year2)}{Tot.Outp.Ind.47(year1)}$$

For most of these data there is no obvious explanation. Considering, for instance, the rapid oil price increase in the middle of the 70-ies, the relative saving of petrol refining products between 1972 and 1977 (in current prices!) is rather amazing.

The increase of material costs of the industry No. 47 during this period is caused, first of all, by the increasing consumption of electrical industrial equipment (this would correspond with the increasing role of industrial automation) and the growing consumption of two service groups: Wholesale/Trade and Transport/Warehouses.

The decreasing use (again in relative terms) of electrical industrial equipment in the second period could be explained by reduction in prices and a higher share of electronic control equipment.

The reduction in ferrous and nonferrous metal consumption in both periods seems to be plausible. But why did the shipments of the metalworking industry to industry No. 47 in relative terms decrease in the first and increase in the second period ? Is this caused, e.g., by changes in the organizational (property) structure of the metalworking industry or even by changes in preparation methods of the I-O table ?

Answering all these questions requires time-consuming analytic work, but is indispensable for any impact study based on the input-output framework. It will be useful to utilize <u>more detailed levels of input-output tables</u> for these purposes. For the U.S. economy, e.g., beyond the 85-sector tables, desaggregated data are available 1). Unfortunately, the sector classification of these tables has been changed from one benchmark year to another, while the aggregated tables are, in principle, comparable.

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1) The classification for the detailed tables includes 365/496 commodities and industries for 1972 and 366/537 for 1977. 1981 is not a benchmark year - since 1980 BEA started to publish also intermediate years on the 85-sector level.

Although the 85-sectoral classification seems to be too aggregated for macroeconomic impact analysis of CIM technology diffusion, it was used by different authors for this purpose (Leontief/Duchin [1986], Howell [1985]).

This short introduction to the subject 'Input-Output and CIM' already gives some idea of the issues connected with this concept. Before analysing general methodological problems of using the input-output approach for macroeconomic impact analysis of the diffusion of new technologies, now some of the previous studies in this field will be described in brief.

4. Previous Input-Output Studies on Macroeconomic Impact of Computer Integrated Manufacturing and Related Technologies. General Methodological Problems

The analysis of technological change within an input-output framework is not a new subject. But rapid development of microelectronics as the motive branch of the present technological revolution and the changes in manufacturing technologies already induced by these basic innovations 1) stimulated new efforts of modeling experts all over the world.

The study 'Microelectronics - Applications, Diffusion and Impacts - The Austrian Case' sets an example for thorough systems analysis of this new technology. The chapter 'Macroeconomic Aspects of Microelectronics' (Fleissner et al. [1981] has been generally recognized as the first systematic application of the input-output approach in this field.

Since new studies were published by other authors. Table 2 gives an comparison of some of these results and the tools used for. So W. Leontief and F. Duchin already in 1983 published the first results of their input-output analysis of employment effects of manufacturing automation (see Howell [1985]). Howell performed a similar study for industrial robot diffusion. Ayres/Brautzsch/Mori in 1987 offered a proposal to incorporate international comparable labor matrices into the INFORUM international system of linked input-output models and started data collection 2).

Regarding the underlying concept of macroeconomic impacts the work of Kinoshita/Yamada, presented at the annual IIASA CIM workshop in 1988 in Stuttgart/FRG, seems to be the most

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1) This term was introduced by Mensch in 1972 to denote innovations, 'which establish new branches of industry, and radical improvement innovations, which rejuvenate existing branches'. (Mensch [1981], p. 500)

2) An overview of the INFORUM system is given by Nyhus [1982] and Porter [1984].

Table 2 - Comparison of Input-Output Studies of the Macroeconomic Impact of CIM and related technologies

Table 2 - Comparison of Input-Output Studies of the Macroeconomic Impact of CIM and Related Technologies

Source	Model used for Analysis	Technology considered	Parameters changed 1)	Scenarios for the rest of the economy
Fleissner et al. [1981]	static I/O, 26 sectors, labor force by sex and 4 educ.levels, econometric demand side model	Microelectronics	A, L	Investment - exogenous (assumptions not mentioned); PCE - demand-side submodel; other final demand: time trend of share of GDP
Leontief/Duchin [1986]	dynamic I/O, 89 sectors, 53 occupations	Automation of Manufacturing, Office Work, techn.change in Health Care and Education	A, B, L	Estimates of the Bureau of Labor Statistics (BLS)
Howell [1985]	static I/O, 86 sectors, 54 occupations	Industrial robots	.	
Ayres/Brautzsch/ Mori [1987]	Proposal: Incorporation of internat. comparable labor matrices into the INFORUM system; 58 sectors, 120 occupations	CIM technologies in general	.	INFORUM: final demand usually endogenous, exc. government expenditures
Kinoshita/Yamada [1988]	8 countries/country groups, 21 sectors, dynamic econometric I/O, trade linkage model	Industrial robots	1, i	final demand: endogenous exc. gov.exp. (?)

1) Abbreviations denote:

A - matrix of direct material requirement coefficients
B, R - matrices of direct capital requirement coefficients (expansion/replacement)
L - Labor matrix (by sector and occupation, sex or education level resp.)
1 - labor requirement function by sector
i - investment function by sector
. - no information available

complex approach. Some important relationships, not allowed for, e.g., in Leontief/Duchin's study 1), were included into the econometric input-output model of these authors. Besides a more comprehensive representation of the national economy, with the help of this model due to a trade linkage submodel it is possible to analyze impacts of robotization on international trade. We will return to this model in chapter 5.

In most of the publications special attention is paid to employment impacts. In the austrian study labor force is subdivided by sex and four education levels, in the other studies - by some 50 or even 120 different occupations. Thus not only the absolute but also the structural effects on employment are considered.

In all studies the scenario analysis approach was used successfully to analyze consequences of different possible diffusion paths and implementation strategies of the technologies under consideration.

Ayres/Brautzsch/Mori [1987] already pointed out several issues of macroeconomic impact analysis of CIM technology diffusion with special respect to the limitations of the input-output approach. Considering macroeconomic impacts of the diffusion of new technologies within some subsystem of the economy like the metalworking industry, it is necessary to take into account some <u>basic problems of the philosophy of the modeling approach</u>. We will focus here on three of them:

1) The <u>predictability of the diffusion</u> of the new technology under consideration and its main parameters;

2) The necessity of some <u>assumptions regarding the dynamics of the entire system</u> while modeling the influence of changes within a subsystem on its environment;

3) The limited ability of abstract economic models to reflect the behavior of complex economic systems and, in particular, processes of <u>adaptation and flexible adjustment to technological changes</u> in a subsystem or processes of mutual compensation of different impacts of the same initial change.

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1) So Ayres/Brautzsch/Mori [1987], analyzing the publications of Fleissner et al.[1981] and Leontief/Duchin (1986), mentioned: 'One drawback of both models is that they do not reflect the feedback of the cost reduction achieved by CIM application to a possible demand increase resulting from lower prices of goods.' (op.cit., p.3)

Some remarks shall be added on each of these topics.

1. Following the technology life-cycle concept, the technologies under consideration are only in the introduction phase and did not enter yet the phase of rapid growth. If, for instance, a logistic diffusion model is used, under these conditions it is rather difficult to obtain statistically significant estimates of the parameters of the model - partly due to the short estimation period, partly because the decisive changes still lie ahead. On the other hand, the cost/benefit performance and the dynamics of input and output parameters of the new technologies can hardly be predicted by extrapolation.

In the studies cited above, relatively rough estimates of the parameters of new technologies and their changes were used. Certainly, these estimates can be improved to some extent by a thorough analysis of case studies and statistical data as they were collected, for instance, within the IIASA CIM project.

In any case the possible influence of uncertainty of these estimates on the forecast results is to be evaluated by means of sensitivity analysis or other methods.

2. While analyzing the impact of CIM technologies on the macroeconomic level, it is necessary to describe the expected dynamics of the whole economy during the forecasting period more or less comprehensively. In the terms of economic models that means, that the future behavior of the exogenous variables of a given model is to be estimated.

In the case of a dynamic input-output model as used, e.g., by Leontief/Duchin [1986], usually non-investment final demand by sector is exogenous. Leontief/Duchin in their study employed estimates of the Bureau of Labor Statistics (BLS) for these variables.

The austrian study (Fleissner et al. [1981]) is based on a model, containing investment as exogenous variables and internalizing the other components of final demand. Personal consumption is explained by a sophisticated demand-side submodel, while government expenditures and foreign trade variables are given as a share of GDP by time trend functions.

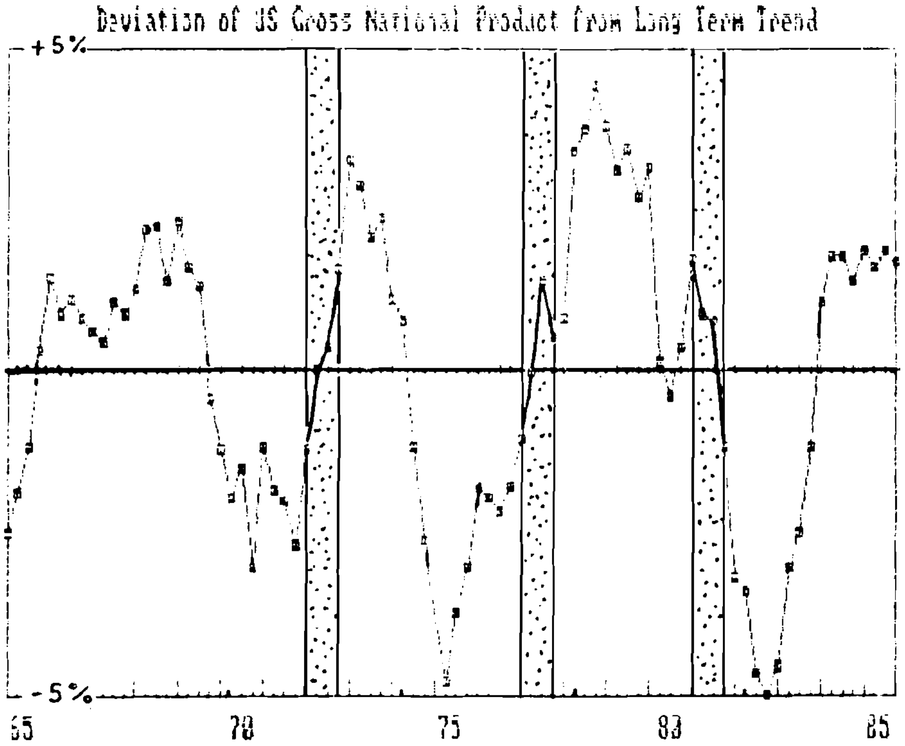
Obviously, it is necessary to determine, to what extent the results of the impact analysis are affected by the choice of these external estimates. Scenario analysis can help to solve this problem. Yet in the studies cited above, scenarios, if used at all, were elaborated in the sense of different diffusion paths of CIM technologies, not for different trajectories of economic growth.

There is another aspect of this issue. If dealing, e.g., with input-output models of the US economy, it must be clarified, whether business cycles should be taken into account in the forecasting process or not. If to a certain extent they could be eliminated from historical data by statistical procedures, this cannot be done, e.g., for the I-O tables. The benchmark years of the latter lie in quite different phases of the business cycles (see fig. 4).

On the other hand, technological change itself is an important determinant of the cyclical behavior of the economy. But it is not the only factor, and the influence of a group of new technologies can well be 'drown' by the influence of other factors as well as by the inertia of the system as a whole.

3. The analysis of the impact of technological change on level and structure of employment by Structural Dynamics theory sets an example for the difficulties of measuring the resulting effect of mutual compensating influences. Thus, e.g., the labor replacement by industrial robots is partially compensated by additional employment in new subcontracting industries, producing robots and their components.

Fig. 4 - The U.S. Input-Output tables in the context of U.S. business cycles.



On the other hand, the productivity increase in the robot-using industry will increase demand for their products and will stimulate investment in this industry, increasing thereby employment, too.

Not only the value, but even the tendency - increase or decrease - of the resulting effect on employment will be very sensitive to parameter changes and, all the more, to changes of the structure of the economic model. With the help of the latter usually complexity is gained at the cost of lower accuracy in details. Balancing mutual compensating influences will multiply this inaccuracy 1).

All the problems mentioned here, might become serious obstacles for using input-output models for the purposes considered in this paper. We must be aware of them when trying to describe an appropriate model structure for our research in the next two chapters.

5. Networks of Macroeconomic Impacts of CIM Technologies

The measurement of macroeconomic impacts of CIM technology diffusion is based on the underlying concepts of possible impacts 2). This concept can be described by some 'conceptual network of causal chains' as developed in chapter 2 (see p. 10/11).

In Bonetto's work [1985] on flexible manufacturing systems one can find such a network written down as a graph (see fig. 5).

So this scheme includes the cost-price-demand feedback not reflected in Fleissner's and Leontief/Duchin's models. In the model of Kinoshita/Yamada [1988] these feedbacks together with other additional impact chains are represented by behavioral equations. The underlying network of causal chains has been described by these authors in verbal form 3). In fig. 6 these relationships are demonstrated as a graph (see page 26).

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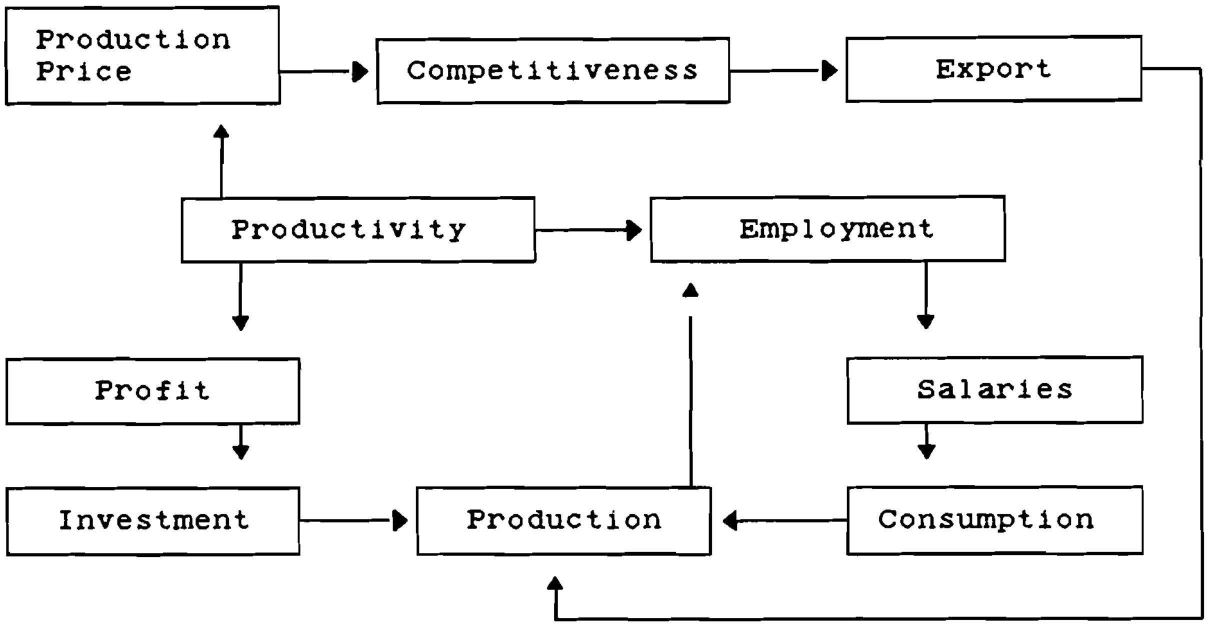
1) In terms of numerical calculations on a computer the calculation of the difference of two almost equal values will cause an increasing percentage error.

2) see chapter 2 of this paper, p. 9

3) Therefor the verbal description in Kinoshita/Yamada (1988), pp. 8-10, has been transformed in a similar way as described by Axelrod's (1976) 'documentary coding methods' (see footnote 3 on p. 11 of the present paper).

Fig. 5 - Network of effects of productivity of Flexible Manufacturing Systems (FMS), (Bonetto [1985], p.161)



The authors distinguish <u>supply side and demand side effects of industrial robot diffusion</u>. As the main driving force for robot application in the countries included in the model they consider labor saving 1). This will improve profitability and/or decrease output price in the robot using industries.

Now with the help of the <u>input-output</u> part of the model it becomes possible to analyze <u>induced price decrease</u> in further related sectors of the economy due to the lower output prices of robot using industries. On the demand-side, besides direct requirements caused by increasing robot shipments, input-output allows to determine <u>induced demand</u> for components and materials, indirectly involved in robot production.

The econometric behavior equations included in the model give the possibility to trace further influences on foreign trade relations as well as upon income distribution, private consumption a.s.o. 'Thus, the initial impact will be multiplied domestically through the interdependent relations of the model' (p.9). On the other hand, the 'effects in the foreign countries will be fed back with a certain time lag to the domestic economy through the channels of trade flow.'

Thereby this model gives a real complex picture of the variety of direct and indirect impacts of a new technology.

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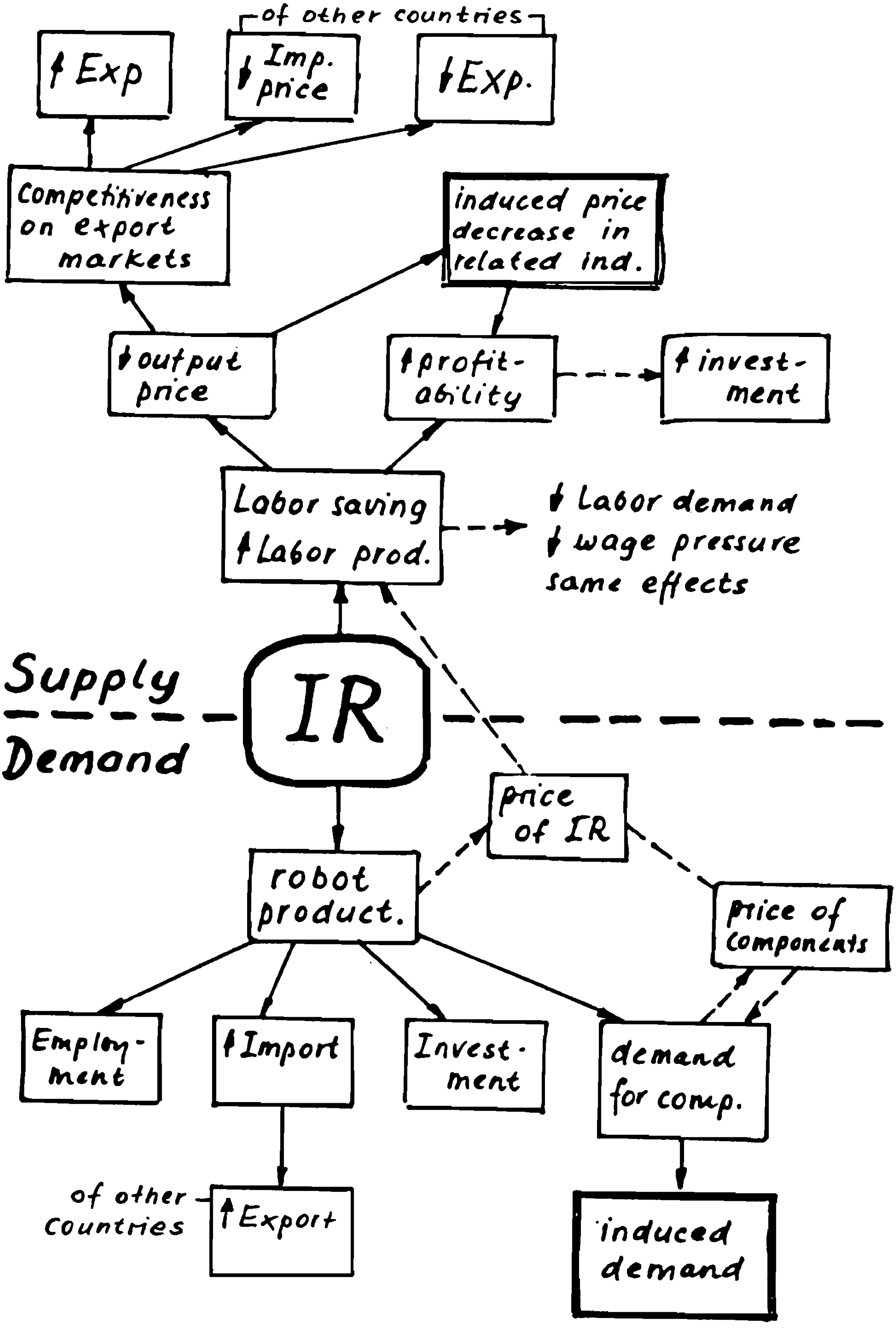
1) 'Wage cost pressure is the most important factor that encourages robot investment' (op.cit., p.9).

Fig. 6 - Causal chains of industrial robot impacts in Kinoshita/Yamada [1988]



Due to the combination of an input-output framework with econometric equations and an international trade flow model effects induced by interindustry relationships can be analyzed together with those caused by complex economic interdependences and international trade linkages.

Yet the complexity of this model has been achieved at the cost of a relatively high aggregation level - 21 sectors. If even within the 85-sector classification of the U.S. input-output tables it is very difficult to identify main CIM components, it will be almost impossible to determine, e.g., increasing demand for robot components induced by growing robot application within a 21-sector framework.

On the other hand, this model does not contain a sophisticated employment side by occupation or education level like other models mentioned above.

In spite of this 'price for complexity' the integration of input-output tables into an econometric framework seems to be a successful approach for studies aiming especially at a comprehensive consideration of all the variety of economic impacts of new technologies.

6. A 13-sector Econometric Input-Output Model of the U.S. Economy

In this chapter a 13-sector econometric input-output model of the U.S. economy will be proposed in order to discuss some issues of practical calculations on macroeconomic impact analysis of CIM technologies.

The main practical problem to be solved while designing a model for this purpose is to clarify, how technological change should be included into the model. Some possible approaches will be discussed here in brief:

1. All studies quoted in chapter 3 (see table 2, p. 20) were based on models of national economies not especially dedicated to technology assessment and, in particular, not explicitly reflecting the mechanism and the driving forces of technology diffusion themselves.

   Diffusion and influence of technology were estimated apart in terms of possible changes of parameters and coefficients of the model. Therefore this approach could be called 'exogenous parameter adjustment'. In some cases rather rough estimates were used (see, e.g., Kinoshita/Yamada [1988], p.11). Leontief/Duchin utilized a lot of data from publications to predict parameter changes. But this information also was only in part based on statistical analysis and often was not that reliable.

Exogenous parameter adjustment could be improved using CIM technology diffusion studies performed at IIASA during recent years.

2. Carter [1987] described an approach to the analysis of technological change within an input-output framework, which is based on a simple decision rule for investment in new technologies depending on the gains from investing in additional capacity or replacing old capacity with new.

   This decision rule is the first step to the integration of a technology diffusion model into an input-output framework.

   Therefor future price changes of inputs and outputs by sector must be predicted. Thus the 'learning curve' concept (see pp.15/16 of this paper) can be reflected immediately in the model. On the other hand, any parameter prediction brings uncertainty into analysis, and even a simple investment decision rule will make it difficult to trace consequences of uncertainty.

   New technologies in a certain sector are represented by a new column of input coefficients for this sector, the capital cost per unit, and the expected price changes mentioned above.

3. For technology impact analysis it might be even not necessary to model the whole national economy, but only some subsystem of those production processes and their economic relationships, which to a certain extent are influenced by the new technology - either directly or indirectly. Influences could be examined on a more detailed level, while a special submodel would explain the diffusion of the new technology.

   Product Chain Analysis software can be used to select the network of flows of goods and of economic relationships, directly or indirectly affected by CIM technology diffusion. This network could be the base, for instance, of a system dynamics framework, used for different scenario simulations.

Among these three alternative modeling approaches we decided for the second one. On the base of the main conclusion of chapter 5 an aggregated econometric input-output model will be proposed, which includes some decision rule to explain the further dynamics of the share of CIM technologies in the output of different sectors of the economy - first of all of the metalworking industry.

Tchijov [1987] carried out a diffusion study for NC-machines in the U.S. metalworking industry. Therefore in the present chapter a model of the U.S.economy will be proposed to continue this research. Since Tchijov referred in his study to the 2-digit subdivision of the U.S. metalworking industry, the same classification is used in the econometric input-output model of the U.S. economy discussed here.

The following table contains the preliminary sectoral classification of this model. Metalworking industry (MWI) has been kept at the 2-digit level, while other sectors of the economy were aggregated. By the way, the subdivision of the MWI is the same as in Kinoshita/Yamada [1988].

Table 3 - Sector Classification of the Model.

No.	Identification	Sectors of the 85-sec. I/O-Table	
1	Agriculture/Forestry	1-4	
2	Mining	5-10	
3	Construction	11-12	
4	Other manufacturing	13-38,64	
5	Final metal products	39-42	
6	Nonelectr. machinery	43-52	Metal-working industry
7	Electrical machinery	53-58	
8	Transport equipment	59-61	
9	Instruments	62-63	
10	Transport/Warehouses	65	
11	Communications	66	
12	Services/Other ind.	67-68,70-79,81-84	
13	Trade	69	
14	Invent.Val.Adjustm.	85	
15	Noncomparable Import	80	

Before discussing the model structure, some words about the integration of econometric equations into an input-output model shall be added. Mori [1987] and Tani [1988] already used the production function apparatus for diffusion studies of industrial robots and NC-machines. That's why we will pay special attention to this particular concept of econometric analysis.

In the practice of econometric modeling there are used different approaches to link an input-output framework with the production function apparatus. One of the problems to be solved by such a linkage is that both input-output and production function to a certain extent perform similar operations, calculating output from production factors or vice versa.

Traditional input-output analysis is connected with the calculation of gross output by industry from final demand by delivering industry. The circle could be closed by some behavior equations explaining final demand components by wages, profits, disposable income and other factors, depending on their part from gross or net output by sector.

In this context production functions by sector would actually duplicate an already existing feedback circle, and they would not make sense, if used for the calculation of output depending on production factors like, e.g., labor and fixed assets. Therefore some econometric input-output models do not use PF at all (see, for instance, Almon et al. [1974] and Levitskij [1977]).

There are two basic concepts to cope with this issue:

a) to make the PF compete with the I-O framework within a disequilibrium model (see, e.g. Uno [1987]);

b) to reverse either the I-O system or the PF to connect one to the other.

In the second case, the production functions could be used, for instance, for computing labor demand from net output and capital stocks instead of calculating output from factors (see Klein [1983]). Another approach is based on the reversion of the input-output part of the model. This can be done , e.g., by calculating final deliveries from gross output (Welfe [1983]).

A different concept is used by Höschel [1985]. In his model delivieries of materials to each sector are being calculated with the help of a distribution share matrix. This matrix was obtained on the base of an input-output table, simply dividing the shipments of every producing industry to each sector by the sum of deliveries of this industry. The sum of materials by purchasing sector together with stocks of gross fixed assets enters the production functions by sector 1).

The comparison of these different approaches is illustrated in the following figure. The structure of the models is simplified extremly to show only the principal differences. Important details are omitted 2).

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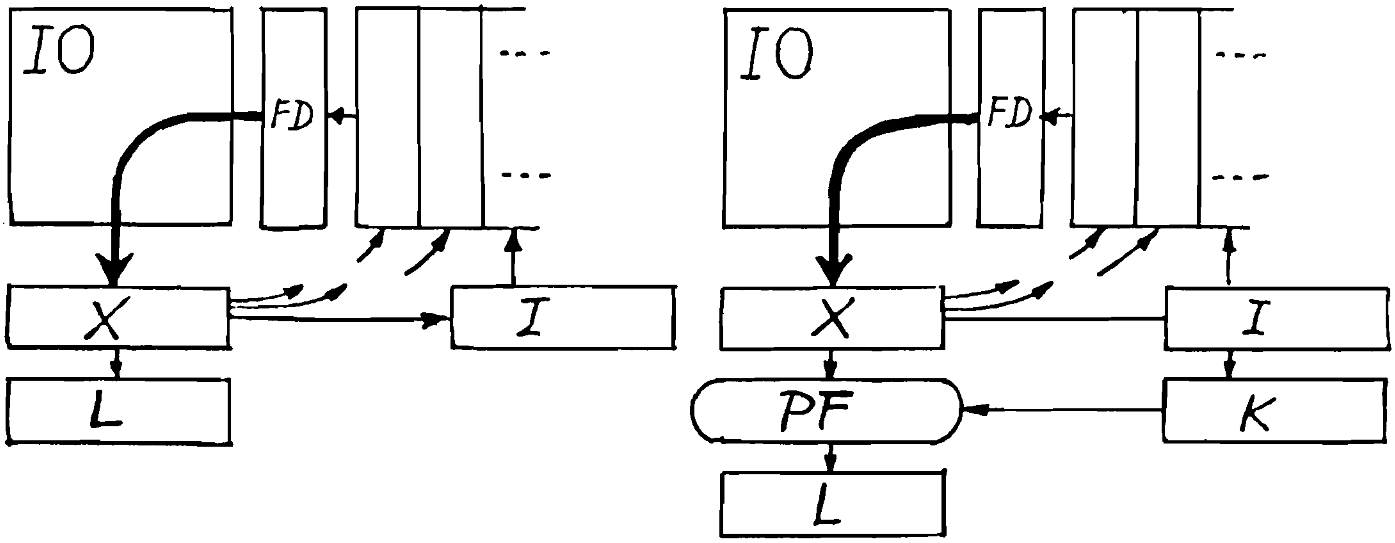
1) Final demand categories are not subdivided by sector in this model, because it has been designed for the prediction of national income, not of sectoral behavior.

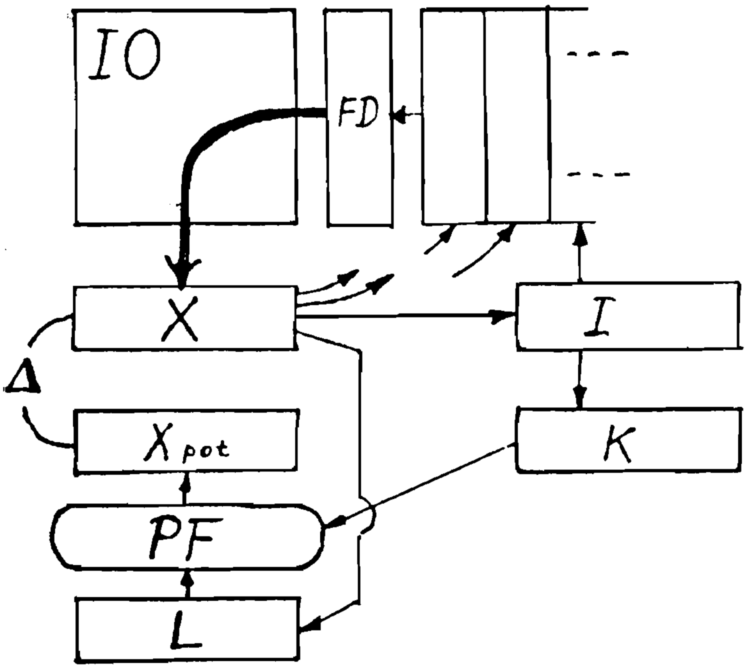
2) The comparison of different econometric models is a rather interesting subject of research. Valuable findings in this field have been obtained, e.g, by Fromm [1973], Klein/Burmeister [1976], Chirinko/Eisner [1983], Salinas/Weyant [1987] (comparison of main U.S. models) and Garbely/Gilly [1984], Boutillier [1984] (using structural analysis methods for econometric model comparison).

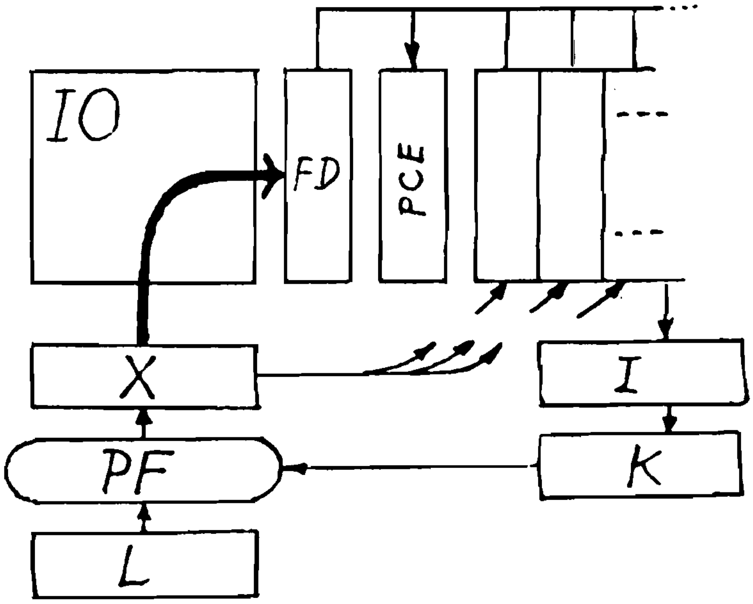
Fig. 7 - Comparison of different approaches to link input-output models with econometric equations



① C. Almon (INFORUM), Levitzkij

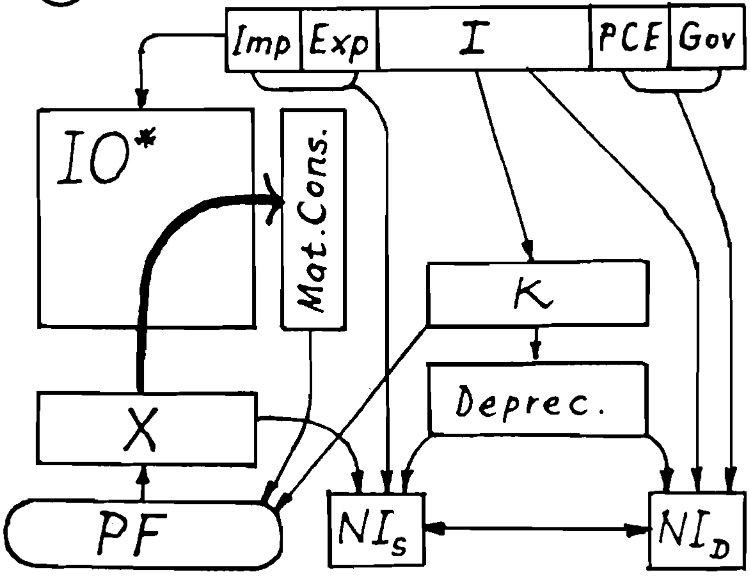
② Klein/Preston (Wharton - Model)





④ W. Welfe

③ K. Uno ("Japanese Industrial Performance")



⑤ H.-P. Höschel

Abbreviations:

IO - input-output table
IO* - distribution share matrix
X - net/gross output
FD - final demand
PF - production function
L, K - labor force / capital stock (by industry)
I - investment by using industry
$NI_{S,D}$ - nat. income (supply/demand)
PCE - personal cons. expenditures
Gov - government purchases

For the purposes of macroeconomic impact analysis of CIM technologies the concept of Klein seems to be the most suitable, mainly for two reasons:

- The input-output table is represented in this model in its 'classical', demand-oriented form. So multiplier effects appear in a similar way like in Leontief's dynamic models.
- The production function is used for calculating labor demand by sector. Thus the results obtained by S.Mori [1987] and A.Tani [1988] applying the production function apparatus to explain robot diffusion can be utilized immediatly.

A possible version of the structure of such a model is described in figure 8, which shall be discussed now in brief.

The key part of the model is an aggregated Input-Output table with a sectoral classification according to Tab. 3 (p.29). It is used here to transform final demand by producing sector into net output by sector. With the help of investment functions by using sectors gross fixed investment is calculated on the base of net output. Now changes in capital stock can be determined. Capital stocks together with net output will enter production functions by sector to compute labor demand by sector.

The non-investment part of final demand by using sector and capital goods not delivered by metalworking industry will be obtained using very rough estimates. For this purpose, e.g., 'bridge vectors' could be used to calculate these values from GNP or from gross fixed investment as a whole.

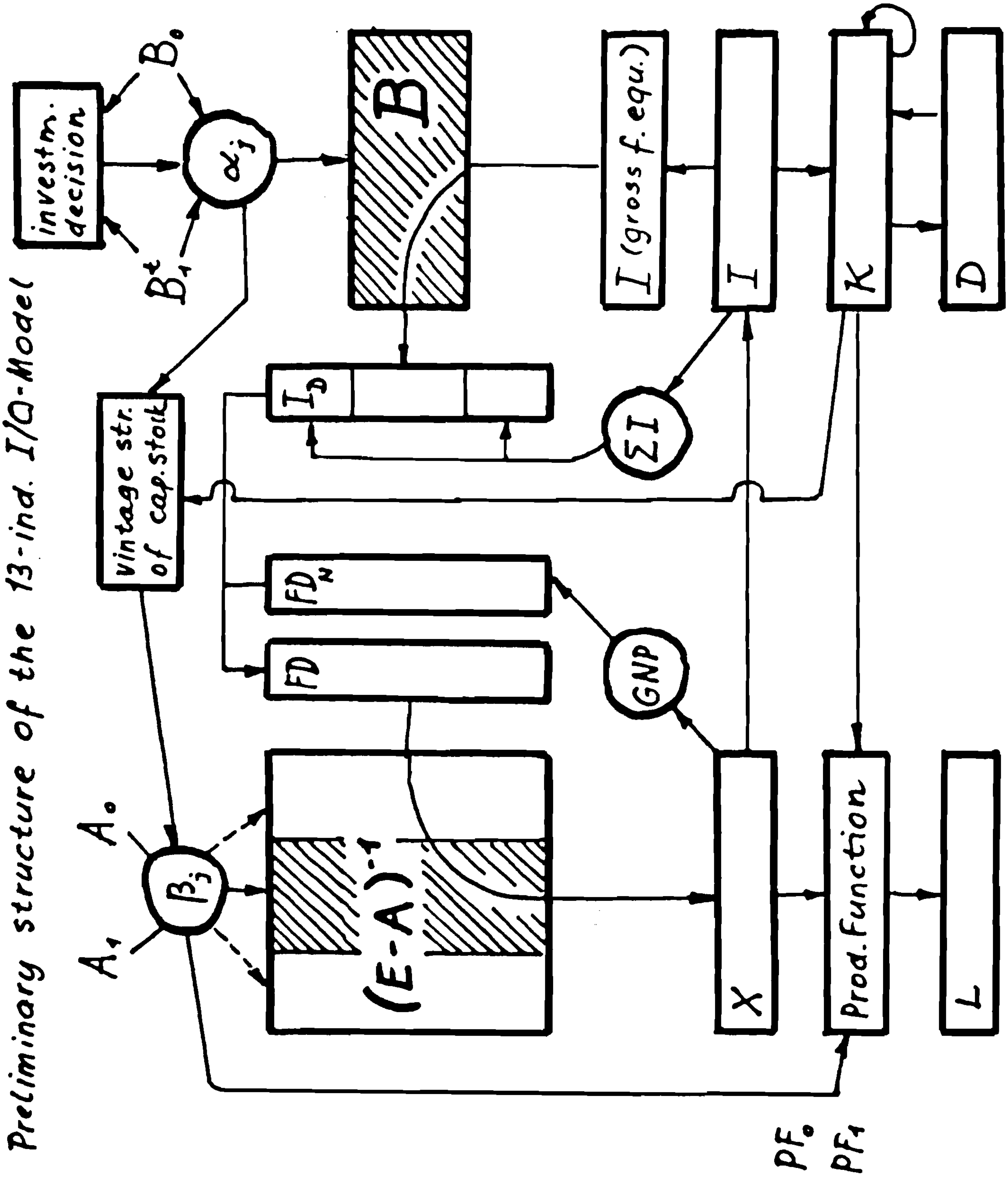
Yet deliveries of capital goods by metalworking sectors must be determined by more sophisticated methods. In Figure 8 one possible approach is demonstrated - the use of matrix B to transform investment for new equipment by using sector into demand for equipment by supplying industry.

On the first step matrix B can be determined on the base of a 'capital flow table' as usually published in connection with input-output tables.

Technological change due to the penetration of CIM technologies is represented here in a way like proposed by Carter [1987]. Some formal investment decison rule is used to decide between investment in old and new technologies depending on expected returns.

After obtaining the share of investment in new technologies $\alpha(j)$ by using sector the corresponding column of matrix B is being modified. Now following the changes of the vintage structure of capital stock one can find out the share of the new technology in sectoral output $\beta(j)$. The latter will allow us to modify both matrix A and the production function (i.e. the labor demand function).

Fig. 8 - The structure of the 13-sector input-output model of the U.S. economy, proposed for macroeconomic impact analysis of CIM technologies



As a precondition for this approach in all three cases - A and B matrices and production function by sector - two data sets must be created: for old and new technology. A special problem will be the specification of the decision rule, which must be able to explain and to predict technology diffusion. In any case this block of the model can be replaced by some 'scenario generator', possibly interactive.

Yet technological change by CIM technologies probably will affect also other variables and relationships even in this relatively simple framework - e.g. inventory change as a part of final demand or investment functions.

During summer 1988 on the base of the 85-sector input-output tables of the U.S. economy for 1972, 1977, and 1981 different aggregated I-O tables were calculated. Main data flows are shown in fig. 9:

1. The 13-sector 'Use' matrix was aggregated from the detailed Use table without any other transformation. That's why for this table all changes in aggregates can be traced back to detailed data.

2. The 85-sector industry/industry table was calculated from detailed Make and Use tables according to Leontief/Duchin [1986] (see Appendix B). Afterwards this table was aggregated and deflated. Value added and total output deflators were approximated from different sources. This table can be used in a model like described above.

3. For needs of product chain analysis information about technological relationships between commodities is desired. Such a commodity/commodity table can be obtained with the help of standard SNA methodology. In this case the industry technology assumption was used to circumvent problems with negative matrix elements 1).

The work on this model was not finished. Nevertheless it is possible to draw some conclusions regarding further research on this subject at IIASA.

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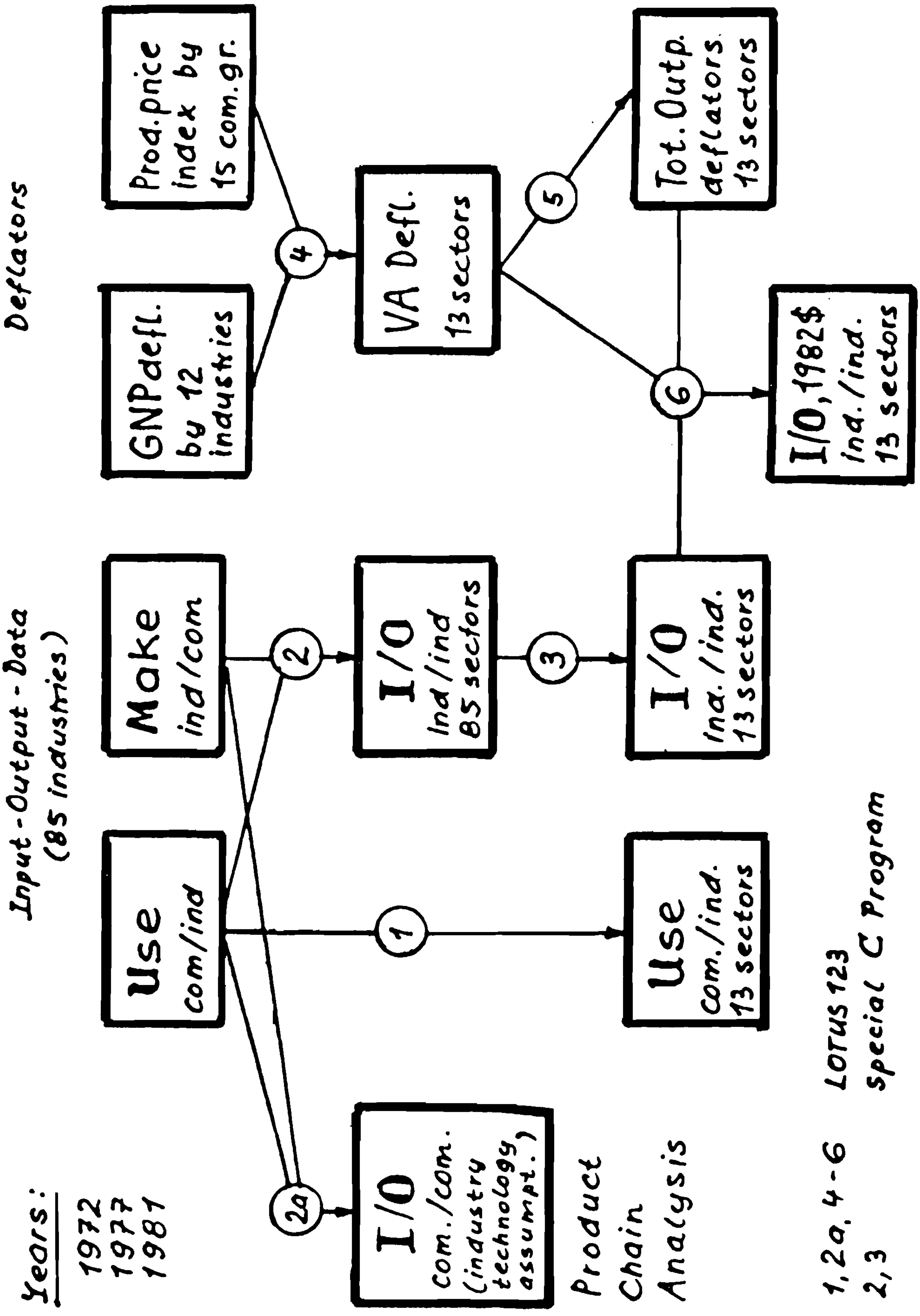
1) There are different approaches to get senseful results for the case of the generally more realistic product technology assumption or some mixed version of both methods (see e.g. Almon [1986], Stahmer [1984]).
The commmodity/commodity tables of direct material requirements published in the Survey of Current Business are also based on tghe industry technology assumption. But they were calculated on a more detailed level than the 85 sector classification. For calculations reported here these data were not used.

Fig. 9 - Calculations performed on the base of 85-sector input-output tables of the U.S. economy



7. Conclusions

1. Input-Output analysis, especially if combined with econometric analysis of additional economic relationships, can be considered as a feasible and productive approach to the study of macroeconomic impacts of computer integrated manufacturing and related technologies.

   With the help of these tools it becomes possible to examine not only direct impacts of new technologies on the economy but induced changes and farther, indirect consequences mediated by interindustry and other relationships as well. At the same time one must be aware of some serious limitations of these methods.

2. One of the main problems of model based macroeconomic technology assessment is the synthesis of relatively aggregated macroeconomic analysis and the inevitably more detailed description of the new technology, its backward and forward linkages, its expected penetration and cost/benefit behavior.

   The choice among different possible approaches to this synthesis (see pp. 27-28) will be determined, above all, by the aims of analysis. The increasing role of government science and technology policy both in market and centrally planned economies is a great challenge to joint efforts of economists, social scientists and engineers in this field.

3. The success of previous studies on input-output based macroeconomic impact assessment of CIM technologies to a great extent was predetermined by

   - the existence of an already 'established' model framework that could be adjusted to this particular subject of analysis and

   - the accumulation of knowledge and data about CIM technologies and their diffusion.

   This conclusion is important for further research at IIASA. Since there is no input-output modeling team in the institute now, it will be impossible to carry out model-based in-house research. On the other hand, the considerable stock of expert knowledge and international data on CIM technologies provides a valuable base for macroeconomic impact studies.

That's why in this field at least external collaboration should be strengthend, if not deciding for a 'revival' of IIASA's in-house INFORUM activities. Possible application areas could be, e.g.:

- providing scenarios of CIM technology diffusion for impact simulations by external collaborators up to closer cooperation with experienced modeling teams in the IIASA member countries

- continuation of the preparation of international comparable labor matrices and comparative analysis of this data

- international comparison of unified indicators of CIM technology diffusion on the macroeconomic level, with special respect to further development of the international division of labor in this field.

In any case it would be useful to continue regular exchange of experience in input-output analysis of CIM and related technologies, e.g. on workshops organized by IIASA.

References

Abbreviations: SCB - Survey of Current Business

C. Almon, M.B. Buckler, L.M. Horwitz, T.C. Reimbold [1974]: 1985: Interindustry Forecasts of the American Economy, Lexington 1974

C. Almon [1986]: Investment in Input-Output Models and the Treatment of Secondary Products, in: Readings in Input-Output Analysis, ed. Ira Sohn, Oxford University Press, New York, Oxford, 1986, p.285

J.P. Ancot (ed.) [1984]: Analyzing the Structure of Econometric Models, Martinus Nijhoff Publishers, 1984

R. Axelrod (ed.) [1976]: Structure of decision, The Cognitive Maps of Political Elites, Princeton University Press, Princeton/New Jersey, 1976

R.U. Ayres, H.-U. Brautzsch, S. Mori [1987]: Computer Integrated Manufacturing and Employment: Methodological Problems of Estimating the Employment Effects of CIM Application on the Macroeconomic Level, IIASA, Laxenburg/Austria, 1987

R. Bonetto [1985]: Flexible Manufacturing Systems, Hermes Publishing Ltd., Paris, 1985

M. Boutillier [1984]: Reading Macroeconomic Models and Building Causal Structures, in: Ancot (ed.) [1984], pp. 35-47

A.P. Carter [1987]: Can Technology Change Too Fast ?, in: Structural Change, Economic Interdependence and World Development, Proceedings of the Seventh World Congress of the International Economic Association, Madrid, Spain; Vol.3, Structural Change and Adjustment in the World Economy, ed. by L. Pasinetti and P. Lloyd, pp. 13-26

R.S. Chirinko, R. Eisner [1983]: Tax Policy and Investment in Major US Macroeconomic Models, Journal of Public Economics 20(1983), pp.139-166

J. Defourney, E. Thorbecke [1984]: Structural Path Analysis and Multiplier Decomposition within a Social Accounting Matrix Framework, The Economic Journal, 94(1984)3, pp. 111-136

G. Dosi [1984]: Technical Change and Industrial Transformation, The Theory and an Application to the Semiconductor Industry, MacMillan,

P. Fleissner, R. Dell'mour, P.P. Sint [1981]: Makroökonomische Aspekte der Mikroelektronik, in: Mikroelektronik - Anwendungen, Verbreitung und Auswirkungen am Beispiel Österreichs, Springer-Verlag, Wien/New York, 1981

G. Fromm [1973]: Implications to and from Economic Theory in Models of Complex Systems, American Journal of Agricultural Economics, 55(1973)2, pp. 259-271

M. Garbely, M. Gilly [1984]: Two approaches in Reading Model Interdependences , in: Ancot (ed.) [1984],pp. 15-34

S. Glaziev [1988]: Elaboration of Scenarios of Computer Integrated Technologies Diffusion, Final Report, IIASA, Young Scientists Summer Programme, 1988

H.-P. Höschel [1985]: A Multisectoral Econometric Model for Analysis and Prediction of the National Income of the GDR, Paper presented at the IXth International Conference 'Models and Forecasts 85', Oct. 29-Nov. 1 1985, Bratislava

D.R. Howell [1985]: The Future Employment Impacts of Industrial Robots - An Input-Output Approach, Technological Forecasting and Social Change 28(1985), pp.297-310

Input-Output [1981]: Proceedings of the Task Force Meeting on Input-Output Modeling (1981), ed. A. Smyshlyaev, CP 82-32, IIASA, Laxenburg/Austria, June 1982

Input-Output [1982]: Input-Output Modeling, Proceedings of the Third Task Force Meeting, 23-25 Sept. 1982, ed. M. Grassini, A. Smyshlyaev, CP 83-S2, IIASA, Laxenburg/Austria, 1983

Input-Output [1983]: Proceedings of the Fourth IIASA Task Force Meeting on Input-Output Modeling, 29. Sept.- 30. Oct. 1983, ed. A. Smyshlyaev, CP 82-S5, IIASA, Laxenburg/Austria, 1983

Input-Output [1984]: Proceedings of the Fifth IIASA Task Force Meeting on Input-Output Modeling, Laxenburg/Austria, 4-6 Oct. 1984, ed. A. Smyshlyaev, Springer-Verlag

Input-Output [1985]: Proceedings of the Sixth IIASA Task Force Meeting on Input-Output Modeling, Warsaw/Poland, Dec.16-18, 1985, ed. I. Tchijov, L. Tomaszewicz, Springer-Verlag

L. Johansen [1978]: Lectures on Macroeconomic Planning, North-Holland Publishing Company, 1978; russ. edition: Progress Publishers, Moscow, 1982, p.186

H.A. Kahn, E. Thorbecke [1988]: Macroeconomic Effects and Diffusion of Alternative Technologies within a Social Accounting Matrix Framework - The Case of Indonesia, International Labor Organization (ILO), Gower, 1988

S. Kinoshita, M.Yamada [1988]: The Impacts of Robotization on Macro and Sectoral Economies within a World Econometric Model, Paper presented at the IIASA Workshop on Computer Integrated Manufacturing, Stuttgart, July 18.-20., 1988

M. Kishi, H. Nakeyasu, K. Noda, K. Taguchi [1986]: Cognitive Map and System Analysis of Maritime Industry, in: Innovation Managment, Proceedings of the Fourth International Conference on Product Innovation Managment, Innsbruck/Igls, Austria, August 26-28, 1985, ed. H. Hübner, Elsevier, 1986, pp.385-399

L.R. Klein [1983]: Lectures in Econometrics, Elsevier, 1983

L.R. Klein, E. Burmeister (ed.) [1976]: Comparative Simulation Studies of the U.S. Economy, University of Pennsylvania Press, 1976

T. Lakso [1988]: The Influence of FMS Technology on the Efficiency of NC-controlled Mach ine Tools, Tampere University Publications 50, Tampere, Finland, 1988

W. Leontief [1986]: Input-Output Economics, Oxford University Press, New York, Oxford, 1986

W. Leontief, F. Duchin [1986]: The Future Impact of Automation on Workers, Oxford University Press, New York, Oxford, 1986

E.M. Levitskij [1977]: Adaptation in Modeling of Economic Systems, Nauka, Siberian Branch, Novosibirsk, 1977 (russ.)
For the model of the U.S. economy, see pp. 54-61.

K. Marx [1867]: Capital. A Critical Analysis of Capitalist Production., Volume I, Progress Publishers, Moscow, 1974

G.O. Mensch [1981]: Basic Innovation and Industrial Growth, in: The Search for Absolute Values and the Creation of the New World, Proceedings of the Tenth International Conference on the Unity of Sciences, November 9-13, Seoul, South Korea, International Cultural Foundation Press, New York

S. Mori [1987]: Social Benefits of CIM: Labor and Capital Augmentation by Industrial Robots and NC Machine Tools in the Japanese Manufacturing Industry (Paper II), WP-87-40, IIASA, Laxenburg/Austria, May 1987

S.B. Noble [1978]: Materials/Energy Accounting and Forecasting Models, in: R.U. Ayres, Ressources, Environment and Economics - Applications of the Materials/Energy Balance Principle, John Wiley & Sons, 1978, pp.95-140

D.E. Nyhus [1982]: Linking Seven Input-Output Models of the Inforum System; in: Input-Output [1982], pp.11-18

L. Pasinetti [1981]: Structural Change and Economic Growth. A Theoretical Essay on the Dynamics of the Wealth of Nations, Cambridge University Press, 1981

C. Perez [1984]: Structural Change and Assimilation of New Technologies in the Economic and Social System, in: Design, Innovation and Long Cycles in Economic Development, ed. C. Freeman, Royal College of Art, London, 1984 London and Basingstoke, 1984

D.A. Porter [1984]: The INFORM-IIASA Family of Input-Output Models; A Brief Historical Review, Progress in 1984, and Future Prospects for Growth; in: Input-Output [1984], pp. 45-50

J. Ranta [1988]: Technological and Economic Factors in the Diffusion Process of Computer Integrated Manufacturing Technologies, IIASA, Laxenburg/Austria, forthcoming

J.A. Salinas, J.P. Weyant [1987]: A Comparison of Macroeconomic Model Structures, Appendix to: Macroeconomic Inpacts of Energy Shocks, ed. B.G. Hickman, H.G. Huntington, J.L. Sweeney, Elsevier, 1987, pp. 269-331

R.L. Sheinin, I.A. Tchijov [1987]: Flexible Manufacturing Systems (FMS): State of Art and Development, WP-87-017, IIASA, Laxenburg/Austria, February 1987

C. Stahmer [1984]: Transformation Matrices in Input-Output Compilations, in: Input-Output [1984], pp.225-236

A. Tani [1988a]: Penetration Mechanism of New Technologies: Integration Formulation from the Company Level to the Macroeconomic Level, WP-88-42, IIASA , Laxenburg, Austria, June 1988

I. Tchijov [1987]: CIM Diffusion: The Case of NC-Machines in the U.S. Metalworking Industry, WP-87-77, IIASA, Laxenburg/Austria, Sept. 1987

K. Uno [1987]: Japanese Industrial Performance, Elsevier, 1987

U.S. Input-Output [1979]: P.M. Ritz, E.P. Roberts, P.C. Young; Dollar Value Tables for the 1972 Input-Output Study, SCB, April 1979

U.S. Input-Output [1984]: The Input-Output Structure of the U.S. Economy, 1977, SCB, May 1984

U.S. Input-Output [1984a]: Mathematical Derivation of the Total Requirement Tables for the 1977 Input-Output Study, Interindustry Economics Division, Bureau of Economic Analysis, U.S. Dept. of Commerce, Washington, May 1984

U.S. Input-Output [1987]: M.A. Planting, Input-Output Accounts of the U.S. Economy 1981, SCB, January 1987

W. Welfe [1983]: Models of the Socialist Economy; in: Klein [1983], pp.208-211

Product Chain Analysis - Using Interactive Graphics for the Analysis of the Network of Interindustry Flows of Materials and Goods

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In economic literature flowcharts often are used to illustrate a network of interrelations, such as interindustry material flows or causal chains within an econometric framework. But beside these illustrative effects, the idea of flowcharts offers powerful analytical possibilities, related to the verification of economic models and their use for decision support.

One of the concepts of economic modeling is based on the evaluation of cumulative impacts of exogenous variables (among them - control variables) on several endogenous variables. These impacts usually are expressed by the so-called multipliers.

In the case of input-output analysis, for example, the multipliers are the coefficients of the Leontief inverse matrix, i.e. the total material requirement coefficients. For econometric models the linkages between the exogenous and endogenous variables are described by the reduced form of the model, which is based on the inversion of the system of equations of the model, too.

Multipliers are obtained as a result of a comprehensive calculation over the entire system of interrelations considered in the model. They can be considered the embodiment of the complexity of the model in the form of a single number. This number reflects the complexity of the economic system, at the same time hiding all the variety of elementary interrelations.

Often the actual values of multipliers are rather amazing, in some cases provoking even serious doubts about the validity of the model solution. This unbelief is caused mainly by two reasons: a subjective one - the unwontedness to look at the system as a whole, and an objective one - distortions of the solution produced by the rigidity of model assumptions, errors in model specification and the inaccuracy of the database.

The solution for both kinds of issues seems to be the uncovering of the most relevant causal chains hidden behind the value of a certain multiplier: in the first case - to convince the user of the relative accuracy of the model and to help him to cope with the complexity of the system; in the second case - to stimulate self-criticism of the model-designer and to provide some measure of the model's inaccuracy in terms of its outputs.

The main idea of 'uncovering' the most important causal chains behind the multiplier or of the decomposition of the multiplier can be described as follows.

Any economic model can be considered an oriented graph with nodes representing products (industries) or economic variables, and arcs showing the dependences 1) between them. Two nodes can be connected by several oriented paths or chains.

The degree of linkage between two neighbouring nodes can be expressed by a number attributed to the corresponding arc. This number could show volumes of flows as well as coefficients, e.g., of direct material requirements (in terms of input-output) or of linear regression (in terms of simultaneous linear equations).

If coefficients are used therefor, a cumulative degree of linkage along a certain path leading from node A to node B can be calculated by multiplying all coefficients attributed to the arcs of this path. After that, one could compute also the total linkage between these two nodes, adding up the cumulative degrees or coefficients of linkage of all paths from A to B 2). This will be the multiplier.

The importance of a particular path can be estimated by retransforming cumulative coefficients to the terms of flows (or absolute factor contributions in the case of behavioral equations).

A similar concept has already been described in some articles (see Noble [1978], Defourney/Thorbecke [1984], Garbely/Gilly [1984], Boutillier [1984]).

S. Noble in his article gave a mathematical description of his 'materials flow analysis' , which is based on input-output tables (op.cit., pp.100/101,111). Defourney/Thorbecke used their 'structural path analysis' within the framework of social accounting matrices (SAM), which aready reflect not only material requirement relationships. The other two articles refer to econometric models, using more sophisticated graph theory concepts.

It is worth noting the purposes the different authors designed structural path methods for in the quoted articles. Noble considers the path product approach a way of 'verification and refinement' of input-output analysis:

> 'Evidently, by examining the chains individually one can pick out and eliminate those that are inappropriate for some reason.' (ibid., p.114)

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1) A-->B means, e.g., 'commodity B is used/consumed for the production of commodity A' or 'A appears as an explanatory variable in the equation with variable B on the left hand side'.

2) Direct and indirect feedbacks will lead to loops within some of these paths. Each of the paths of this kind must be considered an infinite set of paths, distinguished only by the number of passes through this loop. The sum of these loops is the sum of a geometric regression.

Inappopriate chains are caused, for instance, by the level of aggregation of the product classification. Thus if material A is consumed for the production of B, and B for C resp., there will be a product chain A--B--C (C-->B-->A in terms of causality). But due to the high aggregation level possibly A is not being consumed for that part of the output of B which is used during the production of C.

Certainly, this kind of analysis will not basically solve the problem, that actually could be tackled only by disaggregating the product classification. But structural path analysis is at least a powerful verfication tool.

Defourney/Thorbecke emphasize the clarifying and explaining function of this kind of methods:

> 'More precisely, whereas the reduced form provides the solution of a model by expressing endogenous variables as functions of exogenous variables, structural analysis attempts, in addition, to clarify and explain this solution through the study of the transmission of influence within the network of structural relations starting with changes in exogenous variables to their ultimate effects on endogenous variables.'
>
> (op.cit.,p.119)

One should notice, that the aim of structural analysis is not to replace multipliers but to extend their analytical possibilities.

While the results of Defourney/Thorbecke were based mainly on elementary linear algebra, Boutillier [1984] used graph theory methods trying to 'formalize analytical operations, made by an economist when reading macroeconomic models' (op.cit., p.47). In this context structural analysis methods can be considered even a tool supporting the cognitive process of understanding main causal chains of an economic system as they are represented in a macroeconomic model.

Garbely/Gilly [1984] in their article described a method of defining an 'essential feedback vertex set' in a given macroeconomic model, that can be used for the comparison of model structures as well as for increasing the efficiency of the numerical solution procedure of the model.

Independently of these articles within the framework of a large input-output model 1) at the Economic Research Institute of the State Planning Commission of the German Democratic Republic since 1986 has been developed a software package called Product Chain Analysis (EKA - according to the german word ErzeugnisKettenAnalyse).

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1) The Natural-Value Input-Output Model (NWVB), reflecting the material flows between more than 600 commodities and 16 industruies, or ministries

The main idea of the program is to utilize the user-friendly interactive graphic facilities of personal computers for the analysis of the network of interindustry material flows. This network is being displayed on a color graphics screen in the same way as shown in Fig. 2 in this paper. Now one can 'move' within the oriented graph by pressing cursor keys.

It is possible to analyze backward and forward linkages of a given commodity or to select all chains linking two products. In the case of backward analysis, for instance, a product chain over up to ten stages of the production process can be displayed.

On every stage together with the product belonging to the chain up to five more commodities are shown, which are required for the production of the next product of the chain as well. They serve as some 'flexible menue' for the selection of other chains. Therefor it is necessary to move the cursor up or down to the product that shall enter the new chain. Tapping the 'Cursor Left' arrow key will induce the calculation of the materials desired for the production of this commodities. The new chain will be displayed immediatly after the old one has been cleared.

Additionally the program offers some more features:

- The user of the program can select, which values shall be displayed in the boxes of the network graph on the screen: material requirements expressed in absolute volumes or coefficients, in natural or currency units, total or only the part covered by imported resp. domestic materials. Instead of the numbers a small bar graph can be placed in every box as well, showing, e.g., the share of a given material requirement in the overall material deliveries of the product under consideration.

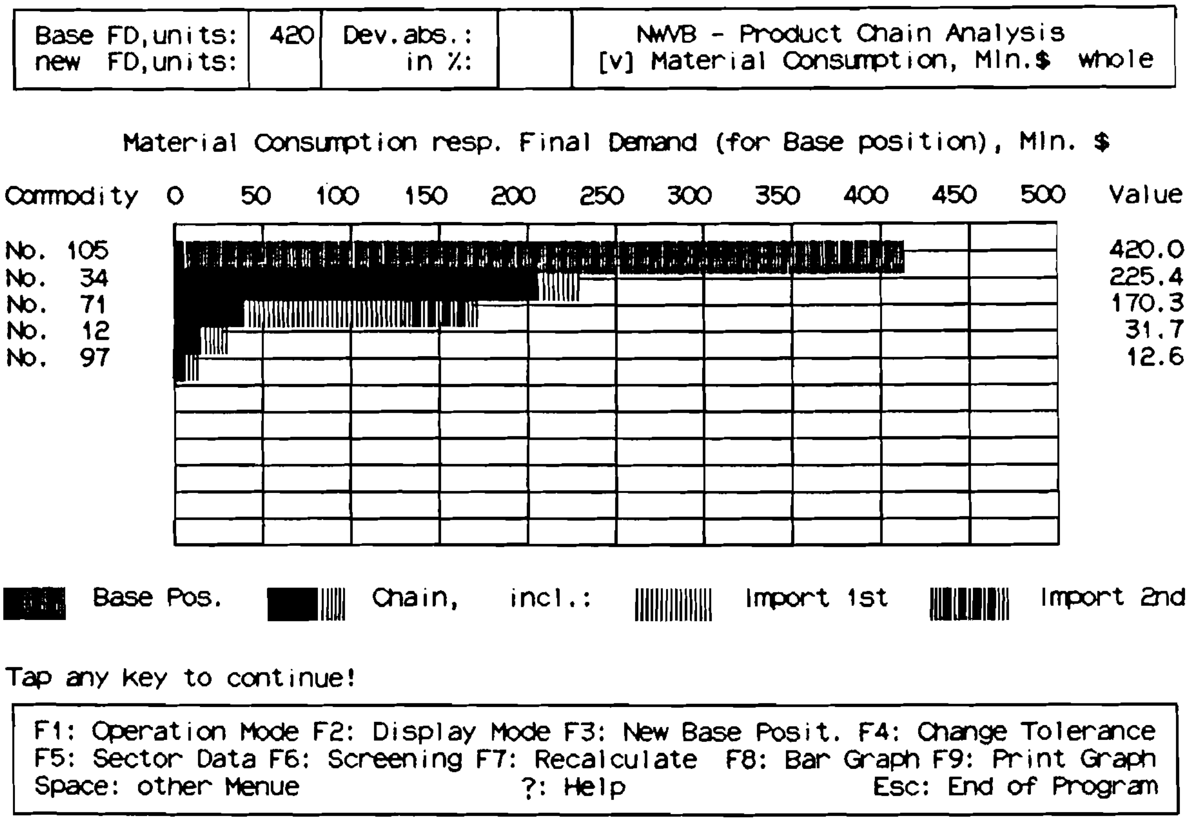
- For every node of the graph (i.e. box of the picture) a short survey of main indicators for the given product can be shown, such as: total output, final demand, material consumption, both in natural and in currency units.

- After a graph has been displayed on the screen, it can be recalculated by changing, for instance, final demand for the base product during the backward analysis procedure.

- For a given product chain a bar graph of the cost structure along the chain can be shown (see Fig. 6). The share of domestic and imported materials is represented in the graph by different colors.

- Matrix mapping as a powerful feature for sparse matrix analysis has been included into the program. The matrix of direct material requirement coefficients is represented by a quadratic table, after the product classification of the model has been subdivided into equal parts in a formal way. Every field of this table corresponds to a quadratic

Fig. 6 - Bar Graph of the Cost Structure of a Product Chain



Base FD,units: 420 Dev.abs.:
new FD,units: in %:
NWVB - Product Chain Analysis
[v] Material Consumption, Mln.$ whole

Material Consumption resp. Final Demand (for Base position), Mln. $

Tap any key to continue!

sector of the matrix and contains the number of coefficients registred for this sector. The relative density of coefficients in the sectors is shown by different colors.

- On the screen the network structure of the graph actually is being transformed into a tree structure of paths through the graph. That's why feedback loops will create infinite 'echo' copies of some subgraphs. Special methods were used to limit these problems. First all displayed chains are selected with a <u>tolerance</u> criteria. Secondly, in the case of self-consumption 1) the sum of the resulting geometric progression will be calculated immediatly after such a node appeared in the graph, so that further 'induced' nodes can be omitted.

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1) Such a self-consumption, i.e. a material requirement of product A for the production of the same product A might be caused by an actual technological feedback or technological losses as well as by the high aggregation level of the product classification of a model, leading, e.g., to the combination of intermediate and final products of a production process within one 'product'.

The program EKA does not depend on a certain product classification. Input data must be provided in a simple ASCII-text-format.

In addition to the aims of structural path analysis noted by the authors cited above, some purposes of product chain analysis are worth mentioning, which strongly influenced the development of this method and software:

- The 'clarifying and explaining function' of such methods becomes more important, if optimization methods are used on the base of input-output models. In this case simplifying model assumptions and the inaccuracy of the database may lead to more serious consequences because of the higher degree of freedom of these models regarding changes in the structure of inputs and outputs.

- If the model is assigned for planning purposes, it is necessary not only to evaluate the efficiency of the current structure of the economy, but to determine, with the help of which particular measures the efficiency could be improved substantially.

  Complex economic relations like, e.g., total requirements of a certain kind of raw materials for some final product, cannot be controlled immediatly - they can be affected only by changing particular processes. Structural path analysis can support the procedure of determining these processes.

Following these ideas, Product Chain Analysis is being extended now by a linkage to optimization tools and by some interactive algorithm for stepwise recalculation of inter-industry shipments. Furthermore, in a new version of the program beyond the 'classical' commodity/commodity approach of input-output analysis different technologies for the production of every commodity can be considered.

According to the concepts of Defourney/Thorbecke [1984], Garbely/Gilly [1984] and Boutillier [1984] it will also be useful to generalize the product chain analysis approach for the analysis of econometric models, thus examining the linkages not only between commodities but economic variables as well.

APPENDIX B

Aggregated Input-Output-Tables of the US-Economy

All calculations were performed on the 85-industry level, using the data published in the Survey of Current Business (U.S. Input-Output [1979,1984,1987]).

For the aggregation the sector classification presented on page 29 of this paper was used.

Two aggregated tables were obtained:

1) The aggregated Use Matrix contains commodity-by-industry intermediate flows and has been obtained by aggregation directly from the Use Matrix published in the SCB. Scrap (sector 81) has been included in aggregated sector No.12. The same procedure was done for final demand, value added and total output (the latter both by industry and by commodity). Calculations were performed using the LOTUS-123 spreadsheet program.

2) The aggregated industry-by-industry Input-Output-Table has been calculated both from the Use and the Make Matrix shown in the SCB. First the method used by W.Leontief/ F.Duchin [1986] was applied on the 85-industry level. According to this methodology the detailed matrix W was calculated by the following formula:

$$\boxed{T = M \langle q^{-1} \rangle \{ U , F \}}$$

T - industry-by-industry intermediate flows
M - industry-by-commodity market-share matrix ('Make' Matrix)
$\langle q^{-1} \rangle$ - inverse of the diagonal matrix of total commodity outputs
U - commodity-by-industry intermediate flows ('Use' Matrix)
F - final demand vectors

After these computations the scrap sector disappears, because according to the Make Matrix scrap is produced in several industries except the industry No.81. Then matrix T was aggregated. The rows showing value added and total output by industry as well as the noncomparable import row can be copied from the aggregated table described under (1).

As LOTUS-123 requires a zeroid presentation of matrices for matrix processing, the tables were too large for an convenient calculation with LOTUS (they should have been divided in different submatrices and recomposed afterwards).

Therefore for these calculations a special C program for sparse matrix handling was written. The calculation of one T matrix (i.e. for one year, including data input from LOTUS-123) requires about 10 minutes on an PC/AT without math coprocessor.