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FACTORY AUTOMATION AND ECONOMIC PERFORMANCE: A MICRO–TO–MACRO ANALYSIS

by

Bo Carlsson, Erol Taymaz
and Kjell Tryggestad

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Postadress
Box 5501
114 85 Stockholm

Gatuadress
Industrihuset
Storgatan 19

Telefon
08-783 80 00
Telefax
08-661 79 69

Bankgiro
446-9995

Postgiro
19 15 92-5

2.92 10.000

FACTORY AUTOMATION AND ECONOMIC PERFORMANCE: A MICRO-TO-MACRO ANALYSIS*

Bo Carlsson
Case Western Reserve University
Cleveland, Ohio 44106

Erol Taymaz
Middle East Technical University
Ankara, Turkey

Kjell Tryggestad
Research Policy Institute
University of Lund
Lund, Sweden

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ABSTRACT

Swedish industry is among the most highly automated in the world. The reasons why Sweden has attained a position of leadership in factory automation are explored in the research project "Sweden's Technological System and Future Development Potential." The purpose of this paper is to examine the implications of automation for various aspects of economic performance.

The first part of the paper reports the results of a series of interviews at the firm and plant level concerning the context of various automation decisions and their consequences. The second part analyzes the results of a questionnaire survey of automation in about 350 Swedish manufacturing entities. The third part is based on a set of simulations on the Swedish micro-to-macro model in which an attempt has been made to model automation. The results of the simulations as well as those of the interviews and the survey demonstrate the complexity of the relationships between automation and various aspects of economic performance. They also show that the impact of automation is highly conditional upon the particular setting in which the automation takes place and upon the ways in which it is implemented.

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A MICRO-TO-MACRO ANALYSIS

Bo Carlsson

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Kjell Tryggestad

2.1 Introduction

Swedish industry is among the most highly automated in the world. Sweden has by far the greatest density (number per worker) of flexible manufacturing systems (FMS) in the world; it is second only to Japan in the density of industrial robots and numerically controlled machine tools and second to the United States in the application of computer-aided design (CAD).

In a current research project ("Sweden's Technological System and Future Development Potential") of which this paper is a part, the reasons why Sweden has attained a position of leadership in factory automation are explored. The purpose of the present paper is to summarize the results of the study with regard to the implications of automation for economic performance, including macroeconomic growth.

A recent search of articles on automation yielded the result that there was only a handful of articles on the subject in economics journals during the period 1985-91 (-- the few that were found dealt mostly with diffusion and labor issues), while there have been numerous articles published in business, management, and engineering journals. The majority of these articles deal with the problem of quantifying the benefits of, and therefore justifying investment in, automation technology.

This state of affairs suggests that there is no easy or general answer to the question, "What is the relationship between automation and economic performance?" Certainly no one has laid claim to any "General Theory of Automation, Productivity, and Growth." Yet one finds economists, government policy makers, businessmen, and engineers making the case for more rather than less automation in industry, apparently assuming that the benefits outweigh the costs even if that cannot be proved. And the fact of the matter is that investments in automation technology are being made every day, in increasing magnitude. How can this be explained?

In order to get at this question, we chose a three-pronged approach. (1) We conducted a series of detailed interviews at the firm and plant levels in order to learn about the context of various automation decisions, and about the consequences of these decisions. The results are summarized in the next section of the paper. (2) Secondly, we surveyed a large number of Swedish firms via a questionnaire in order to get as broad a base as possible for our investigation. The survey is described briefly in Sector 3 and the survey data are analyzed in Section 4. (3) Finally, we designed a set of simulations on the Swedish micro-to-macro model (MOSES) in which we incorporated the findings of these studies. The object of these simulations was to model automation decisions and to get an idea of the nature and order of magnitude of the economic impact of automation at both the micro and macro levels. The simulations are reported in Section 5.

2.2 The Role of Automation in Various Firms: Empirical Illustrations[1]

In order to get in-depth insight as to the context and consequences of automation decisions in Swedish engineering firms, we conducted 23 interviews in 21 firms (listed in Table 1). The persons interviewed were generally those responsible for making and implementing these decisions (plant managers, production managers, chief engineers, and the like). As we expected, the interviews made it abundantly clear that automation techniques play substantially different roles in different firms and in different situations within the same firms. While some installations have been mainly of a productivity-enhancing character, seeking and achieving lower costs per unit of output, others are related to advancement in new product technologies, new market opportunities, and constraints in the labor markets and work environment. In the following, some empirical illustrations of these various roles of automation techniques will be provided, and some of the effects in economic terms will be pointed out. This is simply to illustrate the complexity of the issues which need to be considered in relation to automation, both in the decision-making and in the modeling of these decisions. The cases mentioned here do not represent an exhaustive list of "types" of cases, but they do provide some insight.

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1 This section draws heavily on interview material compiled by Kjell Tryggestad, esp. Tryggestad (1991).

2.2.1 The Simple Cost-Saving Role of Automation

In 1985, one company installed an FMS consisting of more than five machining centers, a large fully automated crane, and 8 automatically guided vehicles. Two years later the economic effects of the installation were followed up. The results were the following:

	Originally expected	Actually achieved
Total project costs (MSEK[2]):	46.6	53.3
Reduction in inventory (MSEK):	16.1	28
Reduction in operating expenses (MSEK):	27.3	19
Reduction in indirect labor (number of workers)	6	less than anticipated
Pay off (in years)	2.4	2.3

Even though the costs of this installation exceeded the original projection, and although the reduction in operating expenses and indirect labor were less than anticipated, the payoff period was actually somewhat shorter than projected. This was due primarily to a larger than expected reduction in inventory.

2.2.2 The Complex Productivity-Enhancing Role of Automation

During the period 1984-1990, one company sought to develop better market orientation of its production. A major

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[2] Million Swedish Crowns

restructuring of the manufacturing activities took place. This reorganization was not driven primarily by cost considerations but rather by a perceived need to reduce the time lag between customer order and delivery. New automation techniques (stand-alone machines and accessories) accounted for 15.6 MSEK of the investment costs. The following data from the project were available in 1990:

	Originally expected	Actually achieved
Reduction in inventory (MSEK)	20	80
Increased turnover of inventory (number of times per year)	2.4	8-9
Reduced delivery costs (%)	40%	n.a.
Reduced costs for unsalable goods (%)	30%	n.a.
Reduction in indirect labor (%)	5%	9%
Increase in direct labor (%)	0	12%
Reduction in administrative personnel (%)	0	4%
Total investment costs (MSEK)	n.a.	35.5
Reduced lead-time for delivery (weeks)	n.a.	12 weeks
Payoff period (years)	n.a.	2.5

During the period 1984-1988, the company increased its physical output (measured in tons of machined cast iron) by 30% and its turnover by 40 % (from $16 to $22 million U.S.). It doubled the types of products manufactured during the 1980s (100 main types in 1990; 45 % of the products were less than 3 years old). From 1984 to 1988, the company reduced indirect labor by 5%. The time from design of a new product to the manufacturing of the prototype was reduced from 25 weeks in 1985 to 12 weeks in 1990. Today the company is a world leader that is able to manufacture at costs well below those of its Japanese competitors while charging a higher price due to its high quality products.

The major reorganization which took place included transition from manufacturing for inventory (i.e., according to plan) to manufacturing to customer order, application of group technology instead of functional layout, integration of CAD/CAM, use of multi-purpose machines, and finally, development of flow-oriented production that reduced lead time in all operations through an on-line manufacturing control system that encompasses every stage in the process. In other words, more customized products, higher quality, shorter delivery times -- in one word: market orientation -- constituted the main rationale behind the change. Cost reduction was merely a welcome by-product.

2.2.3 Automation and New Products

The product/market aspect of automation technology has already been touched upon. This aspect will now be considered in more detail. One of the interviewed companies manufactured titanium parts for airplane engines. Three features are of particular interest: (i) the titanium alloy material used is developed through joint R&D efforts with one major customer; (ii) the parts are manufactured under high precision and quality standards set by the customer. (iii) The hardness of the titanium alloy technology used in the parts requires laser machining. In this instance, (laser) automation technology is a necessary requirement for staying in business under the product specifications determined by the customer; higher productivity through more automation is only a secondary consideration.

Similar product/market considerations prompted another company to invest in automation. In 1987 the company bought an FMS consisting of two machining centers and one robot for material handling. The strategic rationale behind the investment was a desire to increase market orientation by allowing more differentiated and customized products to be manufactured just-in-time. In pure economic terms, the management found it difficult to justify the investment to the board of directors: quantitative measures did not support the decision to invest, while qualitative aspects of anticipated new markets did. The manufacturing facilities prior to the FMS installation were based upon an inflexible transfer line that could handle only a narrow range of highly standardized products in large volumes -- although at low unit costs. Long set-up times were required between different product configurations.

Two years later, having experienced considerable trouble with the integration of the machining centers and the robot, the management acknowledged that the investment could not be justified either economically or strategically. It turned out that the strategic argument simply was not true; customers did not want a more differentiated product but rather more of the same product at lower cost. Therefore, the potential flexibility of the FMS was never utilized -- it only added to cost. The total investment cost was 13 MSEK, but the FMS produced the same product as the transfer line, at only one-third of the speed. In addition, the low capacity of the FMS increased the labor cost since it required operation on Saturdays and Sundays as well. Thus in this case, new and (theoretically) more flexible automation was negatively correlated with economic performance and productivity. But the problem was not in the equipment but rather in the strategic judgement upon which the investment decision was made.

2.2.4 Automation and the Role of Work Environment and Labor Markets

Several of the interviewed companies have invested in automation technology in order to deal with high turnover in the work force and/or recruitment problems in the labor market. This is true particularly for jobs that are characterized by a tough work environment (e.g. welding).

Recently, the first of six robot cells for welding applications was installed in one factory. This automation may reduce labor costs as one worker can now do the job that two workers did before. When all six robot cells are installed, they will probably also reduce costs for absenteeism. Lower labor costs and increased productivity by means of automation may therefore be the result of changes originating in conditions in the work environment and/or labor market.

These examples indicate that while the relationship between automation and productivity may seem positive and simple when measured in isolation from the surrounding context, it is in fact highly complex when considering the role played by other factors, e.g., work environment and labor market conditions. Obviously, different engineering firms face different work environments and labor markets -- not all conduct welding operations, and not all that conduct welding do it under bad work conditions. Thus, it seems reasonable to argue that the rationale for automation will vary with shifting conditions (we have just mentioned a few) across companies within the engineering industry. A simple and positive relationship between the degree of automation and productivity across firms in the engineering industry seems overly optimistic for the same reason.

2.2.5 Summary of the Interview Results

As illustrated in these examples, the measured relationship between the degree of automation and various aspects of economic performance may be weak for several reasons:

* The degree of automation is not necessarily positively related to productivity. Automation may serve other purposes, e.g. it may be necessitated by new products or the requirements of serving particular markets, or by conditions in the work environment and the labor market. Moreover, total costs may rise as a consequence of the investments in a machine but may be more than compensated for by higher returns when new, more valuable products can be manufactured and sold. And indeed, as has been illustrated, if there is a misguided belief in increased market opportunities when using new flexible automation techniques, the result is higher total costs without any increased sales if these opportunities do not materialize.

* The relationship between productivity and economic performance (profitability and market share gain) is complex. A company that has managed to reduce the cost per unit of products no longer in demand can in a narrow sense demonstrate high productivity -- but with declining sales and profits.

Given the apparent complexity of the relationship between automation and various aspects of economic performance, it seemed useful to broaden the systematic collection of data to a larger set of situations than could be handled in the form of interviews, namely through a questionnaire survey.

2.3 Analysis of Automation in the 1989 Survey

A questionnaire survey of economic activity in Swedish industry is conducted annually by the Industrial Institute for Economic and Social Research (IUI) in collaboration with the Federation of Swedish Industries. In the 1989 survey, we appended a set of questions about the degree of factory automation in each of 347 responding units.[3] About 150 of these units answered at least some of the questions on automation.[4]

Descriptive statistics of the main variables used in the analysis are shown in Table 2. Approximately one-half of the

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3 The responding units are financial units, i.e., units for which companies keep separate accounts, e.g. Volvo Cars and Volvo Trucks. In many cases, the units are essentially equivalent to plants.

4 While this implies a response rate of 43 % (at most), it is possible by comparing tables 2 and 3 to get some idea of the differences between those units which answered at least a few of the questions (and thus are included in table 2) and those which answered all the questions (included in table 3).

responding units are in the engineering (metalworking) industry[5]; data for these units are shown separately. The average size of the responding units is fairly large, with 1988 sales of about 1.45 billion SEK (approx. $300 million) in the sample as a whole and 1.61 billion SEK in engineering units. The average employment was about 1300 and 1700 persons, respectively. Thus, engineering units tend to be somewhat larger than other units. They are much more R&D intensive but have lower labor productivity and are also less automated than other units. The latter findings may be surprising at first glance, but the puzzle is resolved once one realizes that the so-called process industries (those producing paper and pulp, chemical and petrochemical products, basic metals, etc.) are non-engineering industries with extremely high capital intensity, high degrees of mechanization, and hence high labor productivity.

As far as the distribution of the labor force by category is concerned, engineering units have more technicians and other specialists and fewer unskilled workers than units in other industries. Surprisingly, engineering units seem to spend far less (although with less variance) on labor training than other units, measured both per employee and in relation to wages and salaries. In terms of the relative distribution of training costs, engineering units spend less on training unskilled workers and more on technicians and other specialists than manufacturing units in general.

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[5] This industry is referred to in the MOSES model as the investment or capital goods sector.

When asked to rank the sources of their competitive advantage -- on a scale from 1 (no advantage) to 4 (very great advantage) -- manufacturing firms in general put product knowledge substantially ahead of quality, process knowledge, and flexibility; access to raw materials seems to be of least importance. For engineering firms, product knowledge and flexibility are the most important sources of competitive advantage, followed by process knowledge and R&D. The differences between manufacturing and engineering units are statistically significant (and positive) with respect to product knowledge, commercialization of existing technology, R&D, flexibility, and negative with respect to access to raw materials. There is no statistically significant difference with respect to process knowledge, the organization or competence of management ("organization"), employee competence, and quality.

As far as the advantages to be gained from automation are concerned, all of the listed options turned out to be of about the same importance, with little difference between manufacturing units and engineering units. The only statistically significant differences suggest that engineering units benefit more from increased flexibility and are less motivated by gaining better control of the production process than manufacturing units in general. (The highest scores in the engineering industry are for uniform quality, less dependence on labor, and improved quality.)

Concerning reasons for not automating, the most frequently cited reasons are that it would not be profitable to do so and that it is not relevant to the unit's production. Few responding units cited lack of competence within the unit or lack of time.

An examination of the correlation matrix yields some interesting results. For manufacturing industry as a whole, the level of automation is highly (and positively) correlated with the level of productivity and somewhat less strongly with profitability; it is not at all correlated with sales growth and is somewhat negatively correlated with the R&D/sales ratio.

For engineering firms, however, the picture is rather different. There is essentially no correlation between the level of automation on the one hand and productivity, profitability, and sales growth on the other. There is a marginally statistically significant (just below the 10 % level) positive correlation with the R&D/sales ratio, however.

These results confirm the interview finding that there is not a simple relationship between automation and other variables but rather a more complex one. Indeed, this has been shown in other studies, e.g. Osterman (1991) who found no relationship at all in the U.S. and Japanese automobile industry between the degree of automation on the one hand and labor productivity and the number of defective products on the other; he concluded that the impact of the technology depends on the context in which it is employed, particularly with respect to work organization (p. 60).

In order to sort out the relationships between the degree of automation and other variables and thus to gain further insight we applied factor analysis to the survey data. The results of that analysis are reported in the following section.

2.4 Factor Analysis of Units in the Automation Data Set[6]

The purpose of factor analysis is to determine which among a set of variables are most closely related to each other. In our case, we wanted to group the observed units in such a way as to enable us to determine whether or not there are distinct differences between different "types" of units, and what the characteristics of each "type" are. For this analysis we made use of a subset of the variables in Table 2, primarily "hard" (objective) data (such as the 5-year growth rate of sales, employment level, etc.). We also used two "subjective" variables. One of these is PROD, defined as the difference between KONKPK and KONKPROC (the importance of product and process knowledge for competitiveness, respectively).[7] A high value of this variable is a proxy for product-driven and a low value for process-driven units. The other "subjective" variable is BOTH which is equal to the sum of KONKPK and KONKPROC. It is a proxy for the importance of knowledge in general, since the KONKPK and KONKPROC variables are highly correlated (i.e., the units that have high scores for the KONKPK variable tend to have high values for the KONKPROC variable also).[8]

Because of the difficulties generated by missing data in this type of analysis, we are forced to restrict the

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[6] This section is based on the factor analysis carried out by Erol Taymaz.

[7] These variables are measured on a Likert scale ranging from a minimum of 1 to a maximum of 4.

[8] The reason for making linear combinations of these variables rather than using them directly is that they are not mutually exclusive; their sum and difference contain additional information.

investigation to 36 units for which data are sufficiently complete.[9] Descriptive statistics of the variables used are shown in Table 3. A comparison of Tables 2 and 3 reveals that the subset contains units which, on average, have more employees, higher levels of automation, productivity, and profit margins but spend less on R&D and have fewer skilled people than the sample as a whole (both engineering and other industries).

The testing procedure indicated that three factors needed to be extracted. The factor structure matrix (Table 4) shows the correlation coefficients between variables and factors.[10] According to the table, the first factor is highly correlated with the growth rate, the profit margin, the share of specialists in employment ("SKILL"), R&D intensity, and the knowledge (BOTH) variable. This factor is taken to represent the dimension of technological progressiveness. In other words, units that have a high value of this factor spend a lot on R&D, employ a relatively large number of specialists, rely on both product and process knowledge, and probably in part because of this, have high growth rates and high profit margins. (It seems plausible that these units consider both product and process knowledge important since new products may require new processes, and new processes may facilitate the development of new products.)

The second factor is significantly positively correlated with labor productivity, the automation level, and, to a lesser extent, with the share of specialists. It is negatively

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9 Four of these units, namely Volvo Aircraft Engines, Volvo Trucks, Volvo Cars, and PLM were included in the interviews referred to in Section 2.

10 Values less than 0.3 are not reported in the table.

correlated with the PROD variable, i.e., it is highly correlated with the relative importance of process knowledge as distinct from product knowledge. This factor is taken to indicate the dimension of process-drivenness.

The third factor is positively correlated with the level of employment, R&D intensity, and the PROD variable, and negatively correlated with the BOTH variable. Hence, it indicates product-driven units that put emphasis on product knowledge and R&D spending (presumably chiefly on product development).

The correlations between these factors and other variables in the dataset are shown in Table 5. The first factor (technological progressiveness) is significantly correlated with the KONKPK, KONKPROC, KONKKOMM (importance of commercialization), KONKFOU (importance of R&D), and KONKFLEX (importance of flexibility) variables. These correlations are in accordance with our interpretation of this factor.

The second factor (process-driven units) is significantly and positively correlated with the KONKRAAV (closeness to raw materials) variable. This reflects the fact that the units that have high values for the second factor are primarily in the paper and pulp (SNI 34) and chemical and petroleum products (SNI 35) industries. This probably also explains why this factor is negatively correlated with the KONKPK (importance of product knowledge) variable: these are highly standardized commodities.

The third factor (product-driven units) is significantly (and negatively) correlated with only one variable, namely KONKPROC (the importance of process know-how).

Upon examination of the score for each unit for each factor, the units in our sample were grouped for the purposes of illustration under the factor for which they obtained the highest score. The results are shown in Table 6. For example, Volvo P (for Passenger cars) scored highest in factor 3 and is therefore referred to as a product-driven unit. Units are located in the table according to their relative scores. In other words, the units at the top of the table are the ones best described by the characteristics of the respective factor. Units with close scores for two variables were placed in the factor for which it obtained the highest score but close to the column for the other factor in the table. For example, one of the Ericsson units had high scores in both Factor 1 and Factor 3. Its location in the table indicates that it scored highest in Factor 1 with an almost equally high score for Factor 3.

The table shows that the "technologically progressive" units include units in the pharmaceutical (Kabi) and telecommunications (Ericsson) industries, while "process-determined" units are found primarily in the petroleum (Statoil), paper and pulp (SCA, Modo, Holmens) and bulk chemicals (Supra) industries. Volvo car and truck units and ABB electrical equipment units, along with Bofors (defense electronics and weapons systems), are examples of "product-driven" units.

Besides the 36 units included in the factor analysis, factor scores were obtained for some of the interviewed units. These are also included in Table 6. In addition, a few other units in the sample of interviewed firms were included in spite of missing data on some variables; in such cases the factor scores were determined by assuming that the values of the missing variables are equal to the sample average. Thus, their place in the table depends on approximations due to missing data. These units are shown in parentheses.

Units below the horizontal line have negative scores for all factors. Therefore, they may be considered a separate group made up of units that produce standard products by means of standard techniques.

In view of Table 6, it is not surprising that the labor productivity and level of automation are highest among the units classified as process driven (F2), while profitability and growth rates tend to be higher in technologically progressive firms which are much less automated. The product-driven group (F3) seems to be divided into one group of engineering units with high factor scores and another made up of units in a variety of industries whose factor scores are low for one reason or another.

What can we conclude from this? It would probably be wrong to conclude from this variety of experience that the degree of automation either is or is not an important determinant of economic performance. The fact that there is not a simple answer does not necessarily mean that there is <u>no</u> answer. The degree of automation per se may have no discernible <u>general</u> impact on economic performance, but in combination with other factors it may be of great importance. It is evident, for example, that automation plays a much different role in the process-driven industries (where it seems to be largely productivity enhancing) than it does in product-driven or technologically progressive industries where the emphasis is on other aspects of performance.

This suggests that using an analytical tool which allows for certain systematic differences among the units being observed (be they plants, firms, or industries) may open up a possibility of gaining further insight than would a conventional macroeconomic model.

Conveniently, the Model of the Swedish Economic System (MOSES) provides exactly that kind of tool. MOSES is a micro-based macroeconomic simulation model developed at the Industrial Institute for Economic and Social Research (IUI) in Stockholm. For an overview of the model, see the Appendix; for a more complete description, see Eliasson (1978, 1985) and Albrecht et al. (1989).

2.5 Simulations on the Swedish Micro-to-Macro Model

In order to gain further understanding of the impact of automation and the orders of magnitude involved, we designed a set of simulation experiments on the Swedish micro-to-macro model. In each case we examined the impact both at the industry level and the macro level of the types of changes described in section 2.2 above. First we ran a reference ("Base") case against which all the other experiments could be compared. 1982 was the base year; each experiment covered a 15-year period; in each case, the change relative to the Base case was made during the period 1983-88. Each case involved two simulations, one in which the change was made only in the capital goods sector and one in which the change was made in all four manufacturing sectors. Only the former simulations are analyzed in the text that follows, but the results of all the simulations are presented in Table 7.

1. The simple cost-saving role of automation (in the form of **cost reduction due to reduced operating expenses, indirect labor, and inventory**) was operationalized as reduced input coefficients. The result was an increase in the GNP and manufacturing growth rates (by 6.4 % and 8.8 %, respectively, over the 15-year period as a whole) relative to the Base case. The productivity growth rate actually declined by some 11 % in the capital goods sector (which is the main supplier of inputs both to itself and to other manufacturing sectors) but rose in the other sectors, with productivity growth virtually unchanged in manufacturing as a whole. The rate of return rose dramatically, especially in the capital goods sector, as did the investment level.

2. The second pair of simulations involved one aspect of the complex productivity-enhancing role of automation, namely **increased flexibility**. This was modeled as a speed-up of the production process, coupled with a reduction in work-in-process inventory. Work-in-process inventories are not negligible; in the engineering firms represented in the model they make up 24 % of the total working capital (slightly more than the capital tied up in plant and equipment (23 %); accounts receivable make up the remaining 53 %).[11]

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[11] The new production process specified to analyze flexibility is similar to the investment specification (see the Appendix): it is specified by a lag function. More precisely, there are now four "stages" of manufacturing. Firms buy inputs and keep inventories of input goods. They then transform inputs to WIP3 (work-in-process at the 3rd stage); then WIP3 is transformed into WIP2, WIP2 to WIP1, and WIP1 to output goods. (For a more detailed specification, see Appendix.) There are now three types of inventories: input, work-in-process (WIP3 + WIP2 + WIP1), and output. Flexible firms are able to convert input inventories in a short time into output inventories.

There are three benefits of flexibility:

1) Flexible firms can adjust quickly to changes in the environment since they require shorter response times than others.

2) They keep less work-in-process inventories.

3) They do not need high levels of output inventories to smooth out unexpected changes in demand.

In this pair of simulations, we increased the flexibility of the units in the engineering sector and in the whole manufacturing sector, respectively, by reducing the throughput time from 0.75 to 0.10 over the first five years of the 15-year experiment.

The main results of the flexibility experiments were the following: there was a slight increase in productivity and output growth in all sectors (except for a decline in productivity growth in the intermediate goods sector) and a positive impact on the rate of return, particularly in the capital goods sector but also in manufacturing as a whole. In spite of this, the investment level was virtually unchanged. Apparently, the freeing up of capital tied up in work-in-process inventory made it possible to achieve higher output and productivity growth rates without raising the investment level.

The flexibility variable can be interpreted as follows. It refers to both throughput time and the level of WIP inventories. In the BASE run its value is 0.75; this means that the mean throughput time is 1.75 (0.75 + 1) quarters. (If its value is zero, all inputs can be converted into outputs within one quarter.) It also shows the level of WIP inventories under steady-state conditions. If a firm with flexibility 0.75 produces 100 units every quarter, then the WIP inventories are equal to 75 units (25 units at each stage).

3. The third pair of experiments involved another aspect of the complex productivity-enhancing role of automation, namely improved managerial and working practices, thereby increasing the output obtainable from a given capital input. This was done by **increasing the marginal output/investment ratio** (referred to in the model as INVEFF).

The main result of this change (compared to the BASE run) was a sharp fall in the output growth rate and a similarly sharp increase in the productivity growth rate for capital goods. The output growth rate declined somewhat in manufacturing but changed barely at all in the economy as a whole. The productivity growth rate increased by 14 % in the intermediate goods sector but rose only modestly in raw materials and the entire manufacturing sector, with a slight decline in the consumer goods sector. Given the nature of the change, it is hardly surprising that the investment level fell, particularly in the capital goods sector. The rate of return was virtually unchanged.

4. The fourth pair of simulations reflected **improved technology**. This was operationalized via improved labor productivity associated with investment in new capital (increased MTEC).

This change resulted in virtually no change in the GNP output growth rate and a slight decline in the manufacturing growth rate. Because of the increased productivity associated with investments, the investment level fell somewhat, resulting in slower output growth in the capital goods sector. The rate of productivity growth increased, especially in the intermediate and capital goods sectors (but a small decline occurred in the consumer goods sector). The rate of return also increased in the capital goods sector.

5. The fifth pair of simulations focused on **improved quality of output** (interpreted as increased potential output, QTOP). This change had little impact on output growth rates and productivity growth, except for a productivity jump in intermediate and capital goods (again with a decline in consumer goods). There was a modest improvement in the rate of return in manufacturing and a somewhat larger increase in the capital goods sector, even though the investment level fell in that sector.

6. Finally, we ran a pair of simulations in which **all of the above changes together** were incorporated. This turned out to raise the output growth rate in the capital goods sector and lower it considerably in intermediate goods and raw materials. The productivity growth rates actually fell in the manufacturing sector as a whole as well as in the intermediate goods sector, while it rose in the capital goods sector. The investment level fell substantially in manufacturing as a whole and even more steeply in the capital goods sector. On the other hand, the rate of return rose by 56 percent in the manufacturing sector and nearly trebled in the capital goods sector. Apparently, the firms had difficulties absorbing all these changes simultaneously and finding outlets for their output.

Taken as a whole, the simulation results reinforce the impression of complex relationships between automation and various aspects of economic performance. The most consistent result is an increased rate of return; this is true in all of the simulations, sometimes dramatically so, and particularly in the capital goods sector. This is, after all, the sector in which the changes are assumed to take place in the simulations analyzed here. A further examination of Table 7 indicates that in most cases the changes are even greater when automation is introduced not only in the capital goods sector but also in other sectors.

The impact of automation on the output growth rate is positive but not impressively so at the level of GNP. The picture is mixed at the manufacturing sector level and even in the capital goods sector. Automation does seem to have a positive impact on productivity growth, but that is not true universally.

Thus, the results in the interviews as well as in the survey and in the simulations confirm the findings in previous studies that the impact of automation is highly conditional upon the particular setting in which the automation takes place and upon the ways in which it is implemented.

Appendix

The Swedish Micro-to-Macro Model[12]

Overview of the Model

The micro-to-macro model is a simulation model of the Swedish economy. Its primary focus is on manufacturing which is therefore modeled in greater detail than other sectors. Other sectors in the model are a government sector, a household sector, and a foreign trade sector. There are also sectors for agriculture/forestry/fishing, construction, oil, electricity, services, and finance, although these are not explicitly modeled.

The manufacturing sector is divided into four industries (raw material processing, intermediate goods, investment goods, and consumer non-durables). Each industry consists of a number of firms, some of which are real (with data supplied mainly through an annual survey), and some of which are synthetic. Together, the synthetic firms in each industry make up the difference between real firms and the industry totals in the national accounts. There are approximately 150 real decision-making units covering about 30 % of industrial employment and output, and about 50 synthetic units.[13]

Firms in the model constitute short and long-run planning systems for production and investment. Each quarter, each firm begins by forming price, wage, and sales expectations and a profit margin target. These expectations and targets are then used as inputs into the production planning process in which each firm sets a preliminary production/employment plan. The basic inputs to this planning process are (1) the firm's initial position (level of employment, inventories, etc.), (2) a specification of the feasible production/employment combinations (determined by past investments), i.e. the firm's production function, and (3) a set of satisfactory production/employment combinations.

The firm's initial (ex ante) production and employment plans need not be consistent with those of other firms in the model. If, for example, the aggregated employment plans for all the firms exceed the number of workers available at the wage levels the firms intend to offer, an adjustment mechanism is invoked to ensure ex post consistency. In case of labor, the adjustment takes place in a stylized labor market, where the firms' employment plans confront those of other firms as well as labor supply. The labor supply is treated as homogeneous in the model, i.e., labor is recruited from a common "pool" but can also be recruited from other firms. However, the productivity of labor depends on where it is employed. This process determines the wage level, which is thus endogenous in the model. In a similar manner, firms' production plans are revised after a market confrontation in the domestic product market, and domestic prices are set.[14]

There is also a capital market where firms compete each quarter for investment resources and where the rate of interest is determined. Given this interest rate, firms invest as much as they find it profitable to invest, in view of their profit targets.

The exogenous variables which determine the potentials attainable in the model are the rate of technical change (which is specific to each sector and raises the labor productivity associated with new, best-practice investment -- see further below) and the rate of change of prices in export markets. The rates of change of these variables are held identical in all the simulations reported here. What drives the model is the incentive system implicit in the feedback mechanisms (particularly in the labor and product markets).

It should be noted further that firms which are unable to reach their profit targets or whose net worth becomes negative, exit from the industry.

The parts of the model most pertinent for our present purposes are presented below.

The Objective Function

Based on market requirements and its own past experience, the firm i sets a target for its rate of return on equity during time period t:

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12 This presentation draws on Eliasson (1989) and Albrecht & Lindberg (1989) in Albrecht et al. (1989).

13 The 150 real decision-making units represent divisions within the 40 largest manufacturing companies plus several medium-sized firms.

14 There is also an export market whose specification need not concern us here.

$$R_{it}^{E} = M_{it}\sigma_{it} - \rho_j + \beta^K + \epsilon_{it}\Phi_{it} \quad (1)$$

$$= R_{it}^{N} + \epsilon_{it}\Phi_{it} \quad (2)$$

where

R_{it}^{E} = rate of return on equity (nominal)
M_{it} = profit margin on sales
σ_{it} = sales/total asset ratio
ρ_j = rate of depreciation of capital in sector j (exogenous)
β^k = rate of price change of capital goods (exogenous)
ϵ_{it} = $R_{it}^{N} - r$
R_{it}^{N} = rate of return on total capital
r = firm's borrowing rate (determined exogenously in the simulations reported here and set equal for all firms)
Φ_{it} = debt/equity ratio

Expectations/Targets

Expectations are generated on an annual basis with quarterly modifications concerning percentage changes in sales, prices, and wages for each firm according to the formula

$$EXP_{it}(V_{it}) = R * EXPI_{it}(V_{it}) + (1-R) * EXPX_{it}(V_{it}); \quad (3)$$

where $EXPI_{it}$ and $EXPX_{it}$ stand for "internally" and "externally" generated expectations, respectively, and V_{it} is the variable about which expectations are being generated. The externally generated expectations and the weighting factor ($0 \leq R \leq 1$) are treated as exogenous parameters, whereas the internally generated expectations are determined by the firm's previous experience with respect to each variable.

In a similar manner, targets are set for the firm's profit margin:

$$TARGM_{it} = MHIST_{it} * (1+EPS_i), \quad (4)$$

where $MHIST_{it}$ is determined by the firm's "profit margin history" as well as the actually realized profit margin in the previous period, and where EPS_i is a constant forcing the firm to increase its profit-margin target as compared with its historical performance.

The Long-Run Production Function

There are two production functions in MOSES, one short-run and one long-run. The short-run production function is used in quarterly production planning in the firm and will be presented below.

The long-run production function for each firm in MOSES is of the following form:

$$Q_{it} = QTOP_{it} * [1 - e^{\frac{-TEC_{it} * L_{it}}{QTOP_{it}}}] \quad (5)$$

where Q_{it} = potential output (in physical units)
$QTOP_{it}$ = the maximum level of output which is approached asymptotically when infinite amounts of labor are used, given a certain level of capital stock.
TEC_{it} = state of technology
L_{it} = firm employment, and
t refers to the time period.

The only factor of production which is explicit in this function is labor. However, the potential output, and hence the productivity of labor, is determined by the state of technology TEC_{it} and $QTOP_{it}$. The exponential term in equation (5) represents the degree of technical inefficiency in the firm. The state of technology at time t in each firm is determined by the previous period's state of technology, the amount of capital, and the level of productivity of new capital:

$$TEC_{it} = \frac{TEC_{it-1}*QTOP_{it-1} + MTEC_{jt}*\Delta QTOP_{it}}{QTOP_{it-1} + \Delta QTOP_{it}} \qquad (6)$$

where

$MTEC_{jt}$ = $MTEC_{jt-1}*(1 + \delta_j)$; (7)
$QTOP_{it}$ = $QTOP_{it-1}*[1 - \rho_j] + \Delta QTOP_{it}$; (8)
$\Delta QTOP_{it}$ = $INV_{it}*INVEFF_{it}$; (9)
INV_{it} = investment made in previous periods and which comes on stream in period t; this is determined endogenously in the model (see eqns. (12)-(17) below);
$INVEFF_{it}$ = the efficiency of newly installed capital (see eqns. (16) and (17) below);
$MTEC_{jt}$ = the level of labor productivity associated with new capital in sector j;
δ_j = the (constant) rate of change of $MTEC_{jt}$ in sector j; exogenous; this parameter is allowed to vary in the first set of simulations below.

$j = 1, \ldots, 4$;
1 = raw material processing sector
2 = intermediate goods manufacturing sector
3 = investment goods manufacturing sector
4 = consumer goods manufacturing sector.

Capital enters the production function indirectly via its effects on labor productivity. Each quarter, firms decide on their level of investment (see below). This investment incorporates best-practice technology which is available to all firms in each industry; the best-practice technology improves at an exogenously determined rate (δ_j) which varies from industry to industry. However, since the efficiency of newly installed capital ($INVEFF_{it}$) varies among firms, the increase in labor productivity resulting from each investment dollar varies from firm to firm. Technological change can therefore be regarded as embodied in new capital, but with the benefits varying individually among firms. The differences in labor productivity that exist initially may increase or decrease over time depending on how the firms fare in the markets, how much they invest, etc.

Note that $QTOP_{it}$, the maximum output attained asymptotically when infinite amounts of labor are used, is not affected by TEC_{it}. (The production function is illustrated in Figure 1.) However, with a better state of technology, the curvature of the production function is increased so that the asymptote is approached more quickly (cf. broken curve in Figure 1).

Also, by hiring more labor, firms can raise their output (although at a diminishing rate); this is represented by movement along Q_{it}. $QTOP_{it}$ is lowered due to the depreciation of capital and raised due to gross investment.[15]

Thus, there are three factors which determine the growth of potential output, namely the level of investment INV_{it}, the efficiency of newly installed capital ($INVEFF_{it}$), and the rate of depreciation of capital ρ_j.

<u>Short-Run Production Planning</u>

The quarterly production planning in the firm starts with the profit target $TARGM_{it}$ which has to satisfy the minimum criterion

$$TARGM_{it} \leq 1 - (EXPW_{it} * L_{it}^{e})/(EXPP_{it} * S_{it}^{e}), \qquad (10)$$

where

$EXPW_{it}$ = the wage rate the firm expects to pay for the current quarter;
L_{it}^{e} = expected employment in the firm;
$EXPP_{it}$ = the net price the firm expects to obtain for its product (net of input goods)
S_{it}^{e} = expected sales volume.

The feasible output, given the firm's labor force at the beginning of the period, is determined by the short-run production function

TEC_{it}

15 For further information on capacity utilization in Swedish industry as represented in MOSES, see Albrecht (1979).

$$Q_{it}^S = (1\text{-}RES_{it}) * QTOP_{it} * (1 - e^{-\frac{\_\_\_}{QTOP_{it}} * L_{it}}) \tag{11}$$

where

Q_{it}^S	=	feasible output volume during the quarter;
RES_{it}	=	"Residual slack fraction", or the ratio between potential and actual output. This is updated quarterly.

The short-run production function is the same as the long-run production function, except that the slack variable now also enters in. For various reasons, firms operate below their potential in the short run (via RES_{it}), just as they do in the long run (via $INVEFF_{it}$).

It should be noted that $QTOP_{it} * (1 - RES_{it})$ corresponds to a standard measure of capacity, i.e., the potential output from existing facilities. There is normally some degree of slack (or X-inefficiency -- cf. Leibenstein 1966). If the firm comes under pressure to fulfill its targets, it reduces the slack. Conversely, lack of pressure may lead to increased slack.

The short-run production planning is illustrated in Figure 2, where the set of simultaneously satisfactory and feasible combinations of output and employment is given by the shaded area. Suppose that, given its initial employment, the firm expects to sell a certain volume of output and that, after adjustment for desired inventory change, this results in the quarterly output plan Q_{it}^e. Then the point (Q_{it}^e, L_{it}^e) becomes the trial output/employment combination. If this point is inside the feasible and satisfactory set, then that point is adopted as the production/employment plan. If, on the other hand, it does not lie within that area, adjustment mechanisms of the sort indicated above for the determination of the employment level are called into play.

Determination of Investment

There are three kinds of assets in MOSES : fixed assets (K1), liquid and other current assets (K2), and inventories (K3). The funds available for investment are calculated in the following way:

$$FUNDS_{it} = CASH_{it} + DESCHBW_{it} - DESCHK2_{it}, \tag{12}$$

where

$CASH_{it}$	= the quarter's cash flow (determined elsewhere in the model)
$DESCHBW_{it}$	= the desired change in debt (or borrowing)
$DESCHK2_{it}$	= the desired change in liquid assets; these assets are kept as a buffer against temporary fluctuations in sales and hence are directly related to the value of sales.

Both $DESCHBW_{it}$ and $DESCHK2_{it}$ are determined elsewhere in the model. The quarter's investment expenditures are then determined by

$$INVEST_{it} = \max [0, (CASH_{it} + CHBW_{it} - DESCHK2_{it})] \tag{13}$$

where $CHBW_{it}$ is the actual change in borrowing of the firm in the current quarter. Should $CASH_{it}$ + $CHBW_{it}$ - $DESCHK2_{it}$ be negative, the firm foregoes investment, and the liquid assets bear the adjustment. The investments in the current quarter do not affect output until at least three quarters later.

Having thus determined current investment, the investment efficiency parameter $INVEFF_{it}$ is determined:

$$INVEFF_{it} = (QTOP_{it} * QP_{it})/K1_{it}, \tag{14}$$

where QP_{it} is the firm's sales price during the quarter (comprising an average of foreign and domestic sales), and where $K1_{it}$ has been updated according to

$$K1_{it} = INV_{it} + (1 - \rho_j) * (K1_{it} * (1 + \beta^K)). \tag{15}$$

Thus, $INVEFF_{it}$ is essentially the firm's incremental output/fixed capital ratio. It may vary over time and among firms for a variety of reasons, including "structural" differences such as differences in type of production, production processes, and degrees of vertical integration. It may also vary because of differences in management techniques and approaches, the amounts of resources devoted to "soft" capital formation in the form of R&D, marketing, etc. Thus, it captures several of the elements of economic competence at the firm level.

For further details, see Albrecht et al. (1989) and Albrecht et al. (1992).

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Table 1 List of Interviewed Firms

Company Name	Main Product
ABB-HV Switchgear	High-voltage electrical switchgear
Atlas-Copco MCT	Mining and construction equipment
Benzler	
Bofors	
Electrolux (CA)	Electrical motors
Flykt	Submersible pumps
Haldex	Equipment for heavy vehicles
IBM - Järfälla	Printers
Landis & Gyr	Measurement and control equipment
LBs Mekaniska verkstad	Automotive components
Lindquist verkstäder	Small mechanical components (job shop)
Mecman	Pneumatic equipment
SAAB Aircraft	Aircraft (military and civilian)
SKF (S)	Spherical roller and ball bearings
Sundsvalls verkstäder	Glass forming machines
Volvo PV Komponenter	Automobile engines
Volvo LV Komponenter	Diesel engines
Volvo Flygmotor	Aircraft engines
Wärtsilä Diesel	Large diesel engines
Åkermans AB (Eslöv)	Excavating machines
Åkermans AB (Lund)	Components for excavating machines

Table 2 Descriptive Statistics of Variables in the Questionnaire Survey

	All industries		Engineering ind.			
Variable	Mean	Std dev	Mean		Std dev	Label
Sales	1453.54	2999.40	1611.31		3249.23	SALES
Sales growth 1983-88	150.24	61.91	154.25		62.91	GROW
Employment	1311.09	2339.17	1727.37	**	3084.21	EMPLOY
Productivity	1023.74	626.41	820.22	**	445.82	PROD88
Profit margin	30.49	15.43	31.68		18.11	PROF88
Automation level	45.50	29.39	35.60	*	27.88	AUTLEVEL
R&D/sales ratio	0.04	0.06	0.07	**	0.06	RDTOTAL
Distribution of labor force						
Executives	0.03	0.03	0.03		0.03	EXEC
Specialists	0.11	0.12	0.14	*	0.13	SPEC
Other white collar	0.23	0.13	0.25		0.11	CLERK
Skilled workers	0.33	0.25	0.30		0.20	SKILWOR
Unskilled workers	0.35	0.26	0.25	**	0.24	UNSKILL
Training costs						
per employee	45.26	340.06	5.42		5.79	TRAINEMP
fraction of wages	0.16	1.36	0.02		0.02	TRAINWAG
fraction of sales	30.84	199.52	7.58		10.55	TRAINSAL
Competitive advantage						
Product knowledge	3.18	0.95	3.37	*	0.79	KONKPK
Process knowledge	2.86	0.95	2.78		1.04	KONKPROC
Commercialization	2.29	1.05	2.55	**	0.94	KONKKOMM
Organization	2.63	0.86	2.59		0.82	KONKORG
Employee competence	2.50	0.90	2.51		0.94	KONKARB
R&D	2.52	1.02	2.77	**	0.90	KONKFOU
Quality	2.95	0.89	2.93		0.89	KONKKVAL
Flexibility	2.83	0.99	3.02	*	0.90	KONKFLEX
Raw material access	1.71	0.97	1.22	**	0.57	KONKRAAV
Advantage from automation						
Lower cost	2.83	0.84	2.93		0.81	FAUTKOST
Less labor depend.	2.94	0.89	3.05		0.85	FAUTBERL
Better control	3.04	0.84	2.86	*	0.78	FAUTKONT
Flexibility	2.49	0.96	2.68	*	0.91	FAUTFLEX
Just in time						
Uniform quality	3.14	0.75	3.09		0.71	FAUTJKVA
Improved quality	3.00	0.81	3.02		0.78	FAUTPKVA
Future advantages	2.79	0.92	2.69		0.89	FAUTKONK
Reasons for not automating						
Not profitable	0.94	0.25	0.96		0.20	OAUTLOON
Too costly	0.53	0.51	0.43		0.54	OAUTKOST
Lacking competence	0.18	0.41	0.17		0.41	OAUTKOMP
No time	0.25	0.45	0.38		0.52	OAUTTID
Not relevant	0.86	0.35	0.83		0.38	OAUTREL
Too small	0.79	0.42	0.64		0.51	OAUTLITE
Being planned	0.75	0.44	0.64		0.51	OAUTPLAN

** and * indicate values which are statistically significantly different (at the 5 % and 10 % level, respectively) between engineering units and other units, using a two-tailed t-test.

Table 3 Descriptive Statistics of Units Included in the Factor Analysis

Variable	Mean	Standard Deviation	Description
GROW	156.51	53.52	Growth rate of sales, 1983-88
EMPLOY	1848.30	3617.76	Employment level
AUTLEVEL	53.36	28.82	Automation level, %
RDTOTAL	.03	.04	R&D intensity (R&D cost/sales)
SKILL	.07	.08	Share of skilled employees
PROD	.33	.92	Product minus process knowledge
BOTH	6.16	1.73	Product and process knowledge
PROF88	34.74	16.99	Profit margin, 1988
PROD88	1223.66	899.11	Labor productivity, 1988

Table 4 Factor Structure Matrix

Variable	Factor 1	Factor 2	Factor 3
GROW	.78072		
PROF88	.71662		
SKILL	.67553	.30662	
BOTH	.56366		-.44715
PROD88		.84615	
AUTLEVEL		.78507	
EMPLOY			.78181
RDTOTAL	.58202		.66321
PROD		-.43910	.55402

Table 5 Correlation Matrix for Variables in the Factor Analysis

orrelations:	F1	F2	F3	CODE	KONKPK	KONKPROC	KONKKOMM	KONKORG	KONKARB	KONKFOU	KONKKVA
F1	1.0000	.0137	-.0830	.2713	.5697**	.4920*	.5153**	.3008	.1858	.5565**	.0580
F2	.0137	1.0000	.0042	-.1134	-.4498*	-.0178	.2376	-.1219	-.1641	-.0014	-.1323
F3	-.0830	.0042	1.0000	.3111	-.1888	-.6670**	.0041	-.2259	-.3221	-.2432	-.0740
CODE	.2713	-.1134	.3111	1.0000	.2041	-.0607	.1723	.0284	.1004	.0861	-.0942
KONKPK	.5697**	-.4498*	-.1888	.2041	1.0000	.4992**	.2657	.5203**	.5837**	.5013**	.4642*
KONKPROC	.4920*	-.0178	-.6670**	-.0607	.4992**	1.0000	.2926	.4144*	.3646	.3279	.2878
KONKKOMM	.5153**	.2376	.0041	.1723	.2657	.2926	1.0000	.2106	.0757	.3891*	.1145
KONKORG	.3008	-.1219	-.2259	.0284	.5203**	.4144*	.2106	1.0000	.7568**	.6078**	.4173*
KONKARB	.1858	-.1641	-.3221	.1004	.5837**	.3646	.0757	.7568**	1.0000	.5031**	.4985**
KONKFOU	.5565**	-.0014	-.2432	.0861	.5013**	.3279	.3891*	.6078**	.5031**	1.0000	.2699
KONKKVAL	.0580	-.1323	-.0740	-.0942	.4642*	.2878	.1145	.4173*	.4985**	.2699	1.0000
KONKFLEX	.5106**	-.1893	-.1033	.0567	.5092**	.3025	.5574**	.4723**	.1422	.5398**	.2795
KONKRAAV	-.0043	.4028*	-.1338	-.4306*	-.1256	.0557	.0015	-.0477	.0024	.0000	.0468
PROD88	.0374	.8459**	-.1235	-.2035	-.3598	.0109	.2448	-.1308	-.1234	-.0692	-.1913
PROF88	.7053**	.2460	.1466	.2192	.1638	.0909	.2986	.1334	.0247	.2837	-.1509
GROW	.7804**	-.1973	-.0626	.1763	.4515*	.1688	.3665	.1395	.0168	.3622	-.0571
EMPLOY	-.0089	.0768	.7802**	.2333	-.0221	-.2195	.0639	-.0778	-.2809	-.2375	.1798
AUTLEVEL	.0495	.7862**	.0898	-.1729	-.1023	.0772	.2406	.0186	.0285	.1225	-.0152
RDTOTAL	.5265**	-.1593	.6163**	.4533*	.1876	-.1166	.2837	.0784	-.0609	.2186	-.0246
SKILL	.6700**	.3166	.0913	.2166	.2485	.1281	.4367*	.1211	.2033	.2533	.0926
PROD	.0323	-.4357*	.5471**	.2387	.3922*	-.6013**	-.0811	.0358	.1482	.1031	.1300
BOTH	.5994**	-.2539	-.4968*	.0638	.8448**	.8854**	.3137	.5327**	.5365**	.4650*	.4311*
TRAINL	.0174	.3979*	-.0203	.0393	-.2825	-.1607	.1800	-.0098	-.0253	.1553	-.1460
TRAINS	-.0686	-.2913	-.0466	.1264	.0035	-.0338	.1894	.0061	.0768	.1139	.1587

Correlations:	KONKFLEX	KONKRAAV	PROD88	PROF88	GROW	EMPLOY	AUTLEVEL	RDTOTAL	SKILL	PROD	BOTH
F1	.5106**	-.0043	.0374	.7053**	.7804**	-.0089	.0495	.5265**	.6700**	.0323	.5994**
F2	-.1893	.4028*	.8459**	.2460	-.1973	.0768	.7862**	-.1593	.3166	-.4357*	-.2539
F3	-.1033	-.1338	-.1235	.1466	-.0626	.7802**	.0898	.6163**	.0913	.5471**	-.4968*
CODE	.0567	-.4306*	-.2035	.2192	.1763	.2333	-.1729	.4533*	.2166	.2387	.0638
KONKPK	.5092**	-.1256	-.3598	.1638	.4515*	-.0221	-.1023	.1876	.2485	.3922*	.8448**
KONKPROC	.3025	.0557	.0109	.0909	.1688	-.2195	.0772	-.1166	.1281	-.6013**	.8854**
KONKKOMM	.5574**	.0015	.2448	.2986	.3665	.0639	.2406	.2837	.4367*	-.0811	.3137
KONKORG	.4723**	-.0477	-.1308	.1334	.1395	-.0778	.0186	.0784	.1211	.0358	.5327**
KONKARB	.1422	.0024	-.1234	.0247	.0168	-.2809	.0285	-.0609	.2033	.1482	.5365**
KONKFOU	.5398**	.0000	-.0692	.2837	.3622	-.2375	.1225	.2186	.2533	.1031	.4650*
KONKKVAL	.2795	.0468	-.1913	-.1509	-.0571	.1798	-.0152	-.0246	.0926	.1300	.4311*
KONKFLEX	1.0000	-.0167	-.1685	.1443	.4988**	.0444	-.0899	.3113	.2444	.1378	.4538*
KONKRAAV	-.0167	1.0000	.3225	-.0026	-.0449	-.0590	.3951*	-.3043	.1075	-.1749	-.0330
PROD88	-.1685	.3225	1.0000	.1915	-.0271	-.0470	.4766**	-.2188	.1902	-.3353	-.1843
PROF88	.1443	-.0026	.1915	1.0000	.4383*	.1260	.1679	.4000*	.4301*	.0633	.1497
GROW	.4988**	-.0449	-.0271	.4383*	1.0000	.0921	-.0997	.3985*	.2906	.2379	.3484
EMPLOY	.0444	-.0590	-.0470	.1260	.0921	1.0000	.1581	.3251	-.0690	.2130	-.1456
AUTLEVEL	-.0899	.3951*	.4766**	.1679	-.0997	.1581	1.0000	-.2316	.2103	-.1689	.0025
RDTOTAL	.3113	-.3043	-.2188	.4000*	.3985*	.3251	-.2316	1.0000	.3858*	.2942	.0301
SKILL	.2444	.1075	.1902	.4301*	.2906	-.0690	.2103	.3858*	1.0000	.0946	.2127
PROD	.1378	-.1749	-.3353	.0633	.2379	.2130	-.1689	.2942	.0946	1.0000	-.1609
BOTH	.4538*	-.0330	-.1843	.1497	.3484	-.1456	.0025	.0301	.2127	-.1609	1.0000
TRAINL	.0851	-.0866	.3687	.1026	.0260	-.0801	.2175	.0621	.2508	-.0907	-.2481
TRAINS	.1952	-.2383	-.2867	-.2565	.0275	-.1109	-.2322	.0870	.0812	.0397	-.0188

Table 6 Classification of Units by Factor

PRODUCT-DETERMINED	TECHNOLOGICALLY-PROGRESSIVE	PROCESS-DETERMINED
VOLVO P		
		STATOIL
	KABI	
	ERICSSO	
ABB STA		
(BOFORS)	ERICSSO	
VOLVO L		
		SCA PUL
ABB REL		
		MODOPAP
	(WARTSILE)	
		GULLFIB
	PAPYRUS	
		HOLMENS
	CEMENTA	
	VOLVO F	
KOSTA B		
		SUPRA A
	ELECTRO	
	KANTHAL	
BILLERU		
	FLYKT I	
FOODIA		
	EDSBYVE	
FELIX		KARLSHA
		WASABR
(ATLAS C)	DUNI BI	MOELVEN
(SKF)	(AKER)	FAGERST
HIAB-FO*	PRODUCE	PLM AB
MARABOU	BULTEN	GISLAVE
	BILLING	
	GRINGES	

Table 7 Simulation Results

	Reference case	Reduced input input coeffic.		Increased flexibility		Increased output/ investmt. ratio		Improved technology		Improved quality		All changes simultaneously	
	BASE	EXP1	EXP2	EXP3	EXP4	EXP5	EXP6	EXP7	EXP8	EXP9	EXP10	EXP11	EXP12
Average annual growth of													
GNP	4.34	4.62	6.32	4.46	4.66	4.39	4.75	4.32	4.56	4.39	4.48	4.36	4.85
Manufacturing	7.12	7.75	10.20	7.16	6.59	6.78	7.76	6.92	7.41	7.15	7.09	7.23	8.50
Raw materials	5.17	4.82	8.94	5.33	5.72	5.74	6.43	5.72	4.99	5.52	5.77	4.74	8.27
Intermediate goods	8.87	8.01	10.48	8.93	7.47	8.70	9.23	8.71	9.31	8.63	8.39	7.51	9.88
Capital goods	6.11	8.30	8.75	6.16	6.22	5.00	6.10	5.50	5.79	6.22	6.21	7.60	7.75
Consumer goods	7.01	7.30	12.18	7.04	6.43	7.39	8.74	7.24	7.95	7.19	7.27	6.99	8.82
Productivity growth of													
Manufacturing	4.21	4.13	5.41	4.29	4.79	4.50	4.77	4.39	4.97	4.44	5.17	3.95	6.58
Raw materials	7.27	7.80	8.42	7.79	9.23	7.35	7.75	7.40	7.84	7.33	7.81	7.24	8.44
Intermediate goods	4.32	4.69	4.29	3.85	4.29	4.92	7.07	4.89	4.80	4.82	3.91	3.39	6.31
Capital goods	4.64	4.14	4.17	4.90	5.21	5.58	5.77	5.27	5.10	5.40	4.53	5.45	5.23
Consumer goods	2.11	2.16	6.15	2.19	3.18	2.05	2.19	1.98	3.56	1.97	5.37	1.87	7.29
Investment													
Manufacturing	28.24	29.24	44.95	28.78	32.00	27.63	25.25	27.90	29.41	28.31	34.73	23.21	31.61
Capital goods	8.20	9.88	9.54	8.24	8.51	6.15	6.75	7.59	7.20	7.14	8.31	4.68	4.49
Rate of return													
Manufacturing	7.78	9.63	13.17	8.49	10.21	7.99	7.97	7.97	7.98	8.00	9.03	12.18	21.90
Capital goods	11.50	20.45	19.44	14.47	15.19	12.56	13.55	12.26	12.37	12.37	12.22	30.24	30.96
Interest rate	13.73	13.12	12.50	13.56	12.63	13.19	13.23	13.48	13.42	13.53	13.43	12.84	11.86

Note: Rate of return net of interest rate and changes in capital goods prices.

BASE: Base case (with FLEXIBILITY=0.75 for all manufacturing firms).

EXP1: Input coefficients decreased 1% quarterly for the capital goods sector (in the period 1983-88)

EXP2: Input coefficients decreased 1% quarterly for all manufacturing firms (in the period 1983-88)

EXP3: Flexibility increased by reducing FLEXIBILITY from 0.75 to 0.1 for the capital goods sector over the period 1983-88

EXP4: Flexibility increased by reducing FLEXIBILITY from 0.75 to 0.1 for all manufacturing firms over the period 1983-88

EXP5: INVEFF increased 2% quarterly for the capital goods sector (in the period 1983-88)

EXP6: INVEFF increased 2% quarterly for all manufacturing firms (in the period 1983-88)

EXP7: MTEC increased 2% quarterly for the capital goods sector (in the period 1983-88)

EXP8: MTEC increased 2% quarterly for all manufacturing firms (in the period 1983-88)

EXP9: QTOP increased 1% quarterly for the capital goods sector (in the period 1983-88)

EXP10: QTOP increased 1 % quarterly for all manufacturing firms (in the period 1983-88)

EXP11: All changes made together for the capital goods sector

EXP12: All changes made together for all manufacturing firms

Figure 1 The Long-Run Production Function in MOSES

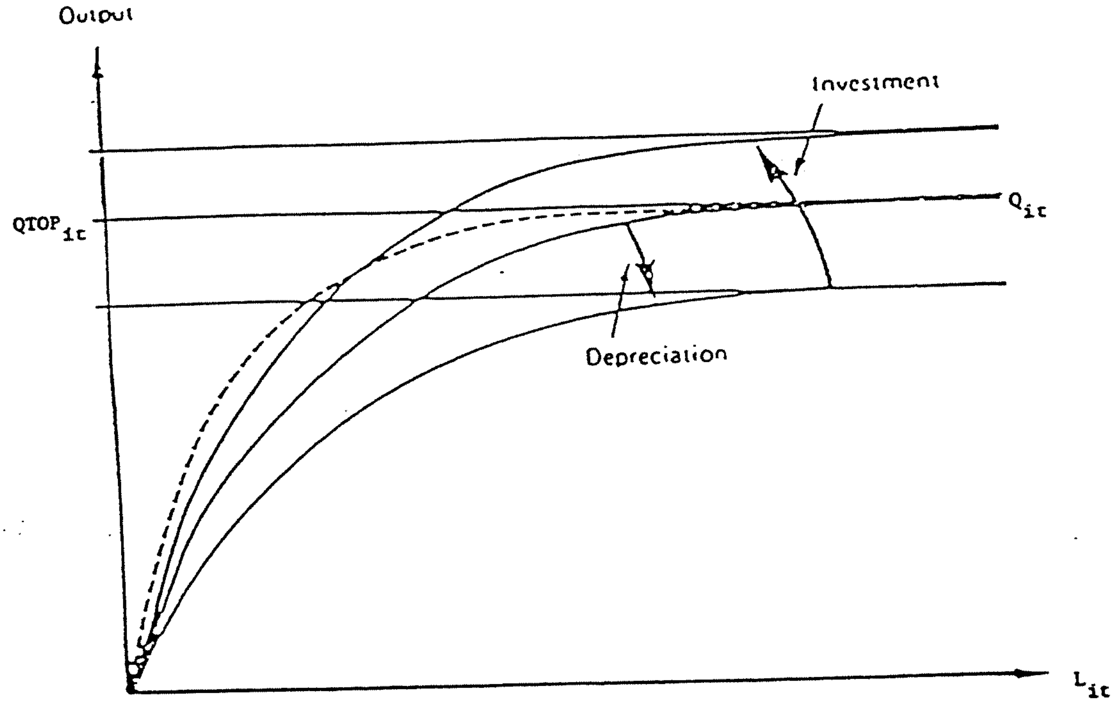

Figure 2 Short-Run Production Planning in MOSES