Some Employment, Income, and Occupational Effects of Microelectronic-Based Technical Change: A Multisectoral Simulation for Canada

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This paper computes some potential employment and income effects of microelectronic-based technical change (MTC) in Canada. The probable upper and lower bounds of the predicted outcomes are determined by simulating alternative scenarios, and by computing the range of feasible post technical change transition paths for each scenario. The occupational shifts required to accommodate the technical change are decomposed into those originating from the supply side (labor productivity and material input changes) versus those induced by final demand changes. These results are presented for an historical period, for the reference or counterfactual (no MTC) path to 1990, and for a 1990 post-technical-change solution. The aggregate results for a plausible scenario indicate that the microelectronic-based technical change modelled in this paper initiates a one-half percent average yearly increase in labor productivity and consequently results in a cumulative displacement of 5 to 6 percent of the (1990) required labor force from 1981 to 1990. Of course, when/if the appropriate structural adjustments take place, those workers will be re-employed and national income will improve correspondingly. An increase in Canada's rate of diffusion (especially vis-à-vis our trading partners) implies more initial displacement, but again the even higher productivity gains (plus the potential for export gains) should ultimately improve national welfare. This conclusion highlights the importance of facilitating the required structural adjustments.

1. INTRODUCTION

There is considerable disagreement about the employment effects of microelectronic-based technical change (MTC). There have been many dire predictions concerning the potential *net* loss of jobs due to au-

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tomation made possible by MTC.[1] However, other researchers disagree.[2] They argue that technological progress promotes increased productivity, real income, and growth; and that if workers are displaced by machines, such technological unemployment should only be temporary since appropriately operating market mechanisms (resulting in changes in relative product and/or factor prices and expenditure of increased incomes) would ensure that those workers are reemployed somewhere in the economy.[3] Therefore, any structural dynamics initiated by technical change, and accommodated by changing patterns of final demand, should induce mobility of factors from declining sectors to new opportunities in growing sectors. Such models would incorporate technological unemployment only as a result of the above adjustments taking place slowly.

According to the latter view, the displacement of workers will be far worse if the new technology is *not* adopted. In the words of Philip Sadler, "adopt new technology and lose some jobs, or fail to remain competitive and lose most or all of your jobs."[4] In other words, in an open economy the increased competition from newly industrializing countries (NICs) and from other advanced industrialized countries makes technical progress (such as MTC) necessary in order to retain export markets and also to prevent import penetration (the loss of domestic markets to foreign producers).

Nevertheless, even in the context of technological unemployment

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[1]Fears concerning the extent of direct displacement are accentuated by statements such as that by the Chairman of General Motors: "every time the cost of labor goes up by one dollar an hour, one thousand more robots become economical" (*New York Times*, Oct. 14, 1981, p. D1); and Professor Tom Stonier has stated that by early next century no more than 10 percent of the labor force will be required to provide us with all our material needs (Stonier, 1981, p. 305). For other examples of such predictions, see Forester (1981).

[2]For example, see Peitchinis (1985) for a well-argued case, although he does not discuss the issue of potential international redistribution of jobs. C. Lester Hogan, the Vice-Chairman of Fairchild Camera and Instrument Corporation, a large U.S. producer of semi-conductor devices, has been quoted as saying that "advancing technology never reduces employment in the long run" (Robinson, 1981, p. 321). IRPP reported in a survey for the Department of Communications that "no economic or statistical evidence supported the proponents of the unemployment side" (Department of Communications, 1982, p. 17). Also, see Zeman, 1985, pp. 141–142. For an overview of both sides of the debate see Browne (1984).

[3]That is, if machines replace workers, either the excess supply of labor brought about by the released workers will result in a decrease in the wage and the associated substitution of labor for capital, or workers will be reabsorbed due to the decrease in unit costs. In the latter case, decreases in prices lead to increases in real income and therefore to increases in the demand for output with the corresponding increase in the demand for labor.

[4]Sadler (1981), p. 295.

occurring because of slow adjustment to a new technological/occupational structure, there are important empirical issues. One of these issues is the potential structural unemployment that is manifested in a mismatch (for occupations, sectors and even countries) of displaced positions and the vacancies created by the compensation or feedback effects.

This paper uses a general equilibrium model to provide some preliminary empirical answers to these and other questions regarding potential technological unemployment for Canada. The modeling methodology is to compute the range of feasible post-technical-change adjustment or transition paths for any particular scenario, and also to compare the effects of alternative scenarios. The latter are determined by different diffusion rates for the new technology, different degrees of dependence on foreign production of the required new equipment, and different degrees of success in export markets.

Section 2 of this paper briefly discusses some characteristics of the new technology and its potential impact. Section 3 summarizes and discusses the structure of the model (MESIM) and the solution method used in this paper. Section 4A presents a comparison of alternative counterfactual paths, and simulation results for aggregate employment and income from alternative scenarios. Section 4B reports some potential occupational implications, decomposing the changes according to those originating from the supply side (productivity and material input changes) versus those from final demand changes. These results are presented for an historical period, for the reference or counterfactual path (no MTC) simulated by the model (MESIM), and also for the solution path when/if the structural adjustments have taken place such that all workers displaced by MTC have been re-employed using the new technological/occupational structure. Section 5 contains brief concluding comments.

2. MICROELECTRONIC-BASED TECHNICAL CHANGE (MTC)

Without wishing to minimize the problems of adjustment (particularly for the individuals affected), earlier fears of sustained widespread technological unemployment in response to, for example, assembly line production and mainframe computers did not materialize. However, there remains an important question as to whether or not the latest new technology (the microelectronics "revolution") has special characteristics that might make its potential (un)employment implications different from earlier technical revolutions.

What is microelectronic-based technical change (MTC)?[5] Combining a microprocessor chip and a memory storage chip on a board results in a microcomputer that can be used to control a robot, a CNC machine tool, CAD devices, or information processing machines such as word processors. The use of the term microelectronic-based technical change (MTC) in this paper refers to the production and application of such machines to production processes and offices. This characterization of the microelectronics revolution is considerably narrower than terms such as "high tech." Nevertheless, semiconductors plus microprocessor, memory, and other integrated circuit chips represent the main raw materials for the burgeoning information economy.

The very rapid advances in semiconductor technologies and integrated circuit designs, plus the associated dramatic decrease in price of these raw materials necessary for MTC, is historically unprecedented. The divisibility of the new technology vis-à-vis mainframe computers, the flexibility of application and the associated rapid speeds of diffusion across the whole economy, all suggest that this technical change may be more revolutionary—in terms of the speed of adjustment required in order to avoid technological unemployment—than those previously experienced. Even with flexible wages and prices, it is possible that the new technology is dominant over the relevant range of factor prices. That is, given the very fast decrease in the costs of the new capital inputs, it is unlikely that wages can decrease enough to induce movement along the new production function even if it allows substitutability. This implies that we must rely on the income effect, the productivity dividend, to generate sufficient new demand to reemploy those workers who are directly displaced by the MTC.

The international implications of MTC will also be particularly important. Because of interdependencies among sectors and countries, the labor displacement may not be in the sector which introduces the innovation and the associated job creation may even be in another country. Many of the relatively labor intensive services (which have in the past absorbed labor displaced from manufacturing industries)

[5]Microelectronics involves the study, design and use of very small devices that depend upon the conduction of electricity through a semiconductor material. An integrated circuit is a semiconductor device containing circuit elements made from a single piece of material and indivisibly connected. The popular terminology "chip" refers to an integrated circuit made from a semiconductor such as silicon. A microprocessor is a large scale integrated circuit which is a central processing unit on a chip. The central processing unit consists of a logic unit, an arithmetic unit and a control unit. See Forester (1981) for a glossary of terms related to the microelectronics "revolution".

are becoming more highly capitalized, which adds to the potential for direct displacement (at fixed output levels). Furthermore, some of these services (for example, those related to information processing) are becoming traded goods which will accentuate international competition and the potential export of jobs. On the positive side, at least in the early stages of the "revolution," the investment required to embody the new technology in the capital stock—and also to increase the capitalization of some sectors—will create jobs. If a country imports the new technology, or the raw materials for that technology, then it loses the feedback (compensation effects) of *producing* those new products but it still achieves the productivity dividend from the more efficient processes which utilize the new equipment. On the other hand, the country could gain *extra* compensation by capturing a larger share of the world market in existing products because of relatively faster diffusion of the new technology and/or by producing new products. In any event, the dynamic trade and investment multipliers are likely to play an important part in the quantity of final demand feedback which is generated.[6]

3. MODELLING THE IMPACT OF MTC

In addition to government task forces[7] investigating the potential impact of MTC, there have been a number of case studies focusing on the production or use of new technology in various industries or sectors—for example, Globerman (1984), Pilorusso (1982), and Werneke (1983). Statistical surveys have also been used to measure the impact of MTC—see, for example, Policy Studies Institute (1985). However, it is difficult to predict the net employment implications of MTC by aggregating industry studies or survey responses. Those studies are very important as sources of information concerning the sectoral detail. Nevertheless, in order to compute the effects for structural unemployment (sectoral and occupational mismatches) and for aggregate (un)employment, it is also necessary to explicitly model the sectoral

[6]It is not just the distinction between process and product innovations that is important from the perspective of growth potential, but also the net new demand initiated by the technological change. Freeman (1981, p. 323) compares microelectronic calculators and watches in this respect. The availability of miniaturized and very inexpensive calculators led to a rapid increase in new demand for this product. However, the introduction of digital watches led to direct substitution for mechanical watches such that little additional demand was created—leading to a loss of jobs in Switzerland and creation of new jobs in Asia.

[7]For example, the Ontario Task Force on Employment and New Technology (1985).

interdependencies; the interactions between supply and demand,[8] such as the feedbacks initiated by the productivity dividend; and the potential for export-led growth, or alternatively, import penetration by those countries that adopt a more rapid diffusion of the new technology.

Earlier literature on formal modelling of the impact of MTC on employment has been surveyed by OECD (1982). Most of these models—notably, Bundesministerium fur Wissenschaft und Forschung (1981) and Whitley and Wilson (1982)—are either input–output models or large scale macroeconometric models with an appended input–output structure. More recent modelling of the employment impact of new technology has been reported in Dungan and Younger (1985), Howell (1985), Leontief and Duchin (1986), Roessner (1985), and Rumberger and Levin (1985).

The model (MESIM) used in this paper was designed to compute some disaggregative (sectoral and occupational) and aggregate employment implications of microelectronic-based technical change. It is an extended Keynes–Leontief-type model that integrates a 39 sector input–output structure and the national income and product accounts into a single general equilibrium framework. That is, an econometric macro model is fitted to real (1971 constant dollars) aggregate time series, while the I–O structure "disentangles" the supply-side implications at a disaggregated level.

MESIM incorporates features of both Bundesministerium (1981)—see Schmoranz (1984)—and Leontief and Duchin (1986). In particular, the demand structure and the "switch" variable technique of computing alternative scenarios is similar to the Austrian study, where as the supply structure with its occupational disaggregation is more similar to Leontief and Duchin (1986). As explained in more detail below, the primary innovation in the static structure of MESIM is our method of computing the range of feasible post-technical-change transition paths for each scenario. There are also important differences in the dynamic structure of MESIM. For example, our method of computing the reference path incorporates substitution trends both from the supply side, such as increasing use of plastics and decreasing use of primary metals, and those initiated by demand, for example, increased demand for services relative to durables. These extensions alleviate some commonly criticized problems of Keynes–Leontief–type models.

The supply side structure has, as basic inputs for each of the 39 sectors, input per unit output coefficients (A), labor input per unit

[8]See, for example, Neary (1981) and Whitley and Wilson (1982).

output coefficients by eighty occupations (QOC); and average weekly working hours (HW). In addition, the input–output data provide a structure (YSTR) by which the components of final demand are allocated across the 39 sectors. Except for the occupational disaggregation, the static structure of the supply side of MESIM is similar to conventional input/output models.[9] The dynamic features are discussed in detail below.

The econometric demand structure models 18 endogenous aggregate expenditure, factor income, and tax variables, given exogenous time series for labor supply; proportion of self-employed in primary and other sectors; construction investment; machinery and equipment investment (this variable is not completely exogenous since it will include the change in investment required to embody the new technology); and change in inventories—with parameters estimated over the period 1956–1983. As mentioned above, the demand structure is similar to that reported in Bundesministerium (1981). That is, in addition to the usual aggregate expenditure functions for consumption, exports and imports, a link between demand and supply is incorporated via an econometric estimation of the time series relationship between factor incomes (wages per employee and profits per self-employed hour) and productivity (per hour). This important link provides a channel through which the productivity dividend or income effect of the technological progress is transmitted to final demand. Econometric relationships are also estimated for taxes on factor incomes and for transfers from the government. Given the appropriate definitions and accounting identities, a very simple model of aggregate expenditure and income is constructed.

Although the demand functions have conventional interpretations, they are not primarily motivated by behavioral theory. Rather the demand model is designed essentially to serve two important functions. Firstly, the out-of-sample extrapolations of the econometric demand relationships provide one side of the general equilibrium reference path solution that will serve as the baseline for comparative scenarios. Therefore, the demand structure was designed to track the data well—using lagged variables, some simple non-linearities, and dummy variables, rather than as a behavioral model. Nevertheless, the dummy

[9]See de Boer and Donkers (1985) for a discussion of the relationship between this specification of the static production technology and other specifications. Also note that imports are not split between intermediate input and final demand use. Although this is clearly possible, it would not add any additional information given the method that the split must be made.

variables correspond to particular economic phenomena (such as the oil price shocks, changes in terms of trade due to exchange rate appreciations and depreciations, major changes in tax policy, etc.), and the estimated coefficients have the expected signs. The second major feature of the demand model is to focus on the final demand feedback or compensation effects in response to the supply side technological change. Therefore, it abstracts from monetary issues[10] and explicitly incorporates the transmission of the real income effect or productivity dividend.

Three general equilibrium solutions are computed for each year: 19xx(R), which is the *reference* (counterfactual) solution—that is, without the microelectronic-based technical change; 19xx(S), which is the solution that incorporates the effects of the MTC *shock* keeping the level (but not the structure) of demand at reference path levels; and 19xx(F), which is the solution in which displaced workers from 19xx(S) are re-employed using the new technological/occupational structure so that we can compute the *final* demand made possible by the new technology. Time paths are generated for each of these solutions by computing them year-by-year from 1979 to 1990 using the converged values for each path in year $t-1$ as starting values for the corresponding path in year t.

The demand side of the model evolves according to projections of the econometric time series model (suitably perturbed by feedback from the MTC shock in the case of 19xx(S) and 19xx(F)). This feedback includes the income effects to factors from the productivity dividend, the change in the level and structure of demand for various occupations (including employees versus self-employed), and the change in the structure of final demand—especially investment, exports, and imports—due to MTC. The supply side evolves according to the reference path chosen and the particular assumptions concerning the impact and the rate of diffusion of the new technology.

One can choose alternative reference (or counterfactual) paths. A particular choice of reference path will affect the *levels* of the variables—particularly the unemployment rate—but will not substantially change the structural impact of MTC or the comparative scenario analysis. For example, some view microelectronic-based technical change as revolutionary, whereas others believe it is evolutionary in the sense that is a continuation of past trends of technical change. Our

[10]Therefore, we were unable to model responses by monetary authorities such as those analyzed by Dungan and Younger (1985).

model allows the historical (1970s) substitution trends for both the supply and demand sides to continue out-of-sample by incorporating the extrapolated rates of change for labor productivity ($1/Q$), materials input structure (A), the structure of final demand across sectors ($YSTR$), and working hours (HW). Therefore, the counterfactual for the revolutionary view (R-R) allows labor productivity and the materials input structure to evolve according to an extrapolation of their rates of change from the 1970s. In that case, the post-technical-change paths (S and F) result from superimposing the impact of MTC on the historical trends. Alternatively, the evolutionary counterfactual path (R-E) subtracts the impact of MTC on $1/Q$ and A from the historical trends so that the former are subsumed in the latter for the post-technical-change paths.

One can easily model other interesting counterfactuals. For example, one extreme version (R-B) which is often used in input-output analysis holds the supply-side structure (HW, $1/Q$, A), plus the structure of final demand across sectors (YSTR), constant at base-year (1979) levels. In this case, the microelectronic-based technical change (MTC) will be the only source of increased labor productivity during the 1980s. Another version (R-H) keeps working hours fixed at base-year levels.

Considerable attention was given to matching the technical change data with the economic structure of the model. For those solutions that incorporate the microelectronic-based technical change (19xx(S) and 19xx(F)), input–output, labor and occupational coefficients are adjusted in an attempt to capture production and three applications of the new technology—microelectronic-based equipment in offices and in production processes plus some associated product innovations.

One source of the widely diverging predictions for the impact of MTC on (un)employment is the failure to incorporate into the technical change data the fact that only a fraction of the tasks of a particular worker will be affected by the technical change and also the fact that often the impact is more similar across occupations than it is across sectors. In other words, analogous to Porat's (1976) classification of the primary and secondary information economies, there are some important sectors (such as the electronic and the machinery and equipment producing sectors) and some important occupations (such as information processing operatives, machinists, assemblers, etc.) which need to be distinguished in modeling the technical change. A further source of the divergent predictions concerning the effect of MTC is the variety of different opinions concerning the rate of diffusion. Like Bundesministerium (1981) and Leontief and Duchin (1986), we have tried to address these issues by using shock data which incorporate the fraction (S) of workers' hours (by sector and occupation, where possible) potentially affected by MTC, the labor productivity using the new technology relative to that using the old technology (P); and alternative rates of diffusion (DF) which tell the model how quickly we wish to approach the potential levels in the various sectors.

The technical change data (S,P,DF,DA) is incorporated into the model by changing the QOC matrix (labor input per unit output by 39 sectors and eighty occupations) and the A matrix (non-labor input per unit output). That is, each element $QOC(i,k)$ of the labor input coefficient matrix is decreased by the product of the existing input coefficient $QOC(i,k)$ times the proportion of those workers potentially affected $S(i,k)$ times the rate of diffusion for that sector and occupation $DF(i,k)$ times the productivity increase due to the technical progress $[1-(1/P(i,k))]$.[11] The new post-technical-change input matrix $QOC(I,K)$ will then incorporate the fact that the same output can be produced with fewer labor inputs. Also, the $A(I,J)$ matrix is adjusted to reflect the change in material inputs due to the technical progress. For example, the *production* of CNC machine tools implies an increase in $A(23,20)$, the input of electrical equipment to the metal fabricating sector, whereas the *use* of CNC machine tools implies a decrease in the inputs of steel per unit output ($A(19,J)$). Analogous adjustments are made to $A(I,J)$ with respect to production and use of robots[12] as well as for computer production.

We have incorporated "switch" variables (as in Bundesministerium (1981) or Schmoranz (1984)) in order to compute alternative scenarios for the post-technical-change solution paths 19xx(S) and 19xx(F). Switch variable $S1$ indicates the rate of diffusion of the new technology. If $S1$ equals 0 the rate of diffusion (DF) is at empirically observed and extrapolated levels. If $S1$ equals 1 then DF is 50 percent faster than the empirically observed rates, whereas if $S1$ equals 2 the diffusion

[11]This was the method used to adjust QOC for office applications using S, P and DF data adapted from Leontief and Duchin (1986, chapter 3). For production process and product applications, the S, P and DF data were adapted from surveys reported in Bundesministerium (1981)—see also Schmoranz (1984). Since that data was disaggregated by sector only, it was necessary to use a shift-share matrix (incorporating information adapted from Leontief and Duchin (1986, chapter 2), data on the sectoral distribution of potentially affected occupations and on stocks of new technology equipment, etc.) to implement the potential change in occupational structure for production applications of the MTC. Details are available from the author on request.

[12]Howell (1985) and Leontief and Duchin (1986) create a new sector for robot production while we subsume it in the metal fabricating industries (sector 20). The adjustments to the A matrix are considered a first step until more detailed technical information can be obtained.

rates are such that the full potential of the new technology (as measured by S) is in place by 1990. Switch variable *S*2 captures different degrees of dependence on foreign production of new equipment. *S*2 equals 0 implies that the same fraction of investment is imported as for the reference solution path 19xx(R). On the other hand, when *S*2 equals 1 all the investment related to the new technology equipment is imported. Finally, *S*3 allows us to perturb the export path.

As mentioned above, the impact of the MTC shock on the level of investment is uncertain. While new machines must be produced (or imported), machines using the technology which has been replaced no longer need to be produced. Therefore, the net effect on the level of machinery and equipment investment (*VEST*2), and consequently on employment, depends on the relative size of these two effects. Following Bundesministerium (1981), we have incorporated an initial estimate by leaving the level of *VEST*2 in 19xx(S) equal to that in 19xx(R) but changing its structure across sectors. In particular, the change in *VEST*2 required to embody the new technology[13] is subtracted from all the manufacturing sectors (according to the proportion of machinery and equipment investment in each sector along 19xx(R)) and added back into the sectors that would produce the new equipment, again according to their relative shares of investment. This procedure is designed to capture a shift in the structure of required investment towards those sectors, while keeping the overall level fixed—that is, the amount of new investment is approximately the same as the amount of displaced investment. Of course, since the structure has changed, there will still be employment consequences. Also, when *S*2 equals 0 we will now be importing more in the new equipment producing sectors and less in the other manufacturing sectors, although the level of imports will be approximately the same (approximately since a slightly higher proportion of investment is imported in the former than in the latter). However, when *S*2 equals 1 imports will not only have a new structure but will also be considerably higher.

Therefore, the international links are modelled using estimated import and export functions and separating investment which is imported from that which is domestically produced. Then the implications of faster diffusion at home relative to the rest of the world (and *vice versa* of course) are analysed by computing scenarios which perturb, by a

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[13]Based on an estimated 1983 cost of 0.07 (0.007) million 1971 dollars for equipping a production (office) work place and a nonlinear adjustment schedule $3/X$, where X is the year being simulated minus 1979.

chosen percentage, the fraction of investment that is imported ($S2$ switch setting) and/or the export path ($S3$ switch variable setting). $S3$ equals 0 implies that exports are at empirically observed and extrapolated levels while $S3$ equal to 1 increases exports (by five percent in this paper).

Thus, scenario (000) proceeds with empirically observed settings for the three switch variables whereas, for example, scenario (111) has 50 percent faster diffusion, complete dependence on foreign production of new technology equipment, and increased exports (meant to capture the increased price and non-price competitiveness of a faster diffusion rate than our trading partners); while scenario (211) is the same as (111) except that available new technology is fully incorporated by 1990—that is, DF^{90} equals one. Obviously many different scenarios (based on different combinations of the switch settings) can be computed. Our tables report some alternatives.

In summary, one computes three solutions (19xx(R), 19xx(S), 19xx(F)) for each year. Two post-technical-change paths (19xx(S) and 19xx(F)) are computed for each scenario relative to the chosen reference or counterfactual path (19xx(R)) which the alternative scenarios have in common. Solution path 19xx(F), which computes the implication of reemploying workers displaced by the microelectronic-based technical change (as measured by 19xx(S) versus 19xx(R)), is very important because it incorporates the general equilibrium feedback, unlike Bundesministerium (1981) and other Keynesian-Leontief-type models criticized by Whitley and Wilson (1982) and OECD (1982). Although it might be useful to model the behavioral reactions to the MTC explicitly (that is, trace *the* predicted transition path from 19xx(S) to 19xx(F)), this is very difficult to do empirically.[14] Computing two post-technical-change paths—19xx(S) which illustrates the displaced workers keeping demand at reference path levels, and 19xx(F) which determines the levels of final demand made possible by the MTC when all the displaced workers have been reemployed using the new structure—provides the range of feasible transition paths. If adjustments are instantaneous such that all workers displaced by the new technology are reemployed immediately according to the new technological/occupational structure, then 19xx(F) will be the relevant post-technical-change path. At the other extreme, if output remains at reference path

[14] If detailed elasticity estimates of the type presented in Denny and Fuss (1983) for occupational demand by a Canadian telecommunications firm were available for all industries, the applied general equilibrium method would be a particularly attractive alternative methodology.

(no MTC) levels throughout the simulation, then none of the displaced workers will be re-employed so that the predicted post-technical change path is 19xx(S). Of course, additional structure on the model provided by, for example, a theory of skill acquisition, could predict a particular transition path from 19xx(S) to 19xx(F).

Therefore, MESIM does not explicitly use relative prices to predict a particular transition path (see footnote 15). However, all the substitution trends embodied in the yearly, constant dollar, input/output use (input), output, and final demand data matrices at the medium (39 sector) level of aggregation are utilized. Furthermore, due to the dominant nature of the new techniques introduced by MTC, the income effects and the dynamic substitution effects (such as the changes in the structure of investment as the new technology is embodied) are quantitatively more important than intraperiod substitutions induced by relative price changes.[15] Nevertheless, the dynamic evolution of cost prices and the factor price frontier could be computed as output for MESIM.

Finally, uncertainty concerning the speed of diffusion and the composition of the feedback (for example, the amount of required investment which is imported versus produced domestically) is incorporated by means of a comparative scenario analysis. This methodology seems to provide a useful first step for an analysis of the employment implications of MTC.

Explicit introduction of existing capital stocks as well as stocks of the new technology equipment (for example, robots, CNC machine tools, CAD/CAM equipment, and information processing machines such as word processors) would allow investment flows to be linked to new stocks in a dynamically consistent manner. However, this would involve the difficult issue of modeling capacity utilization (Helliwell and Chung (1984) and Leontief and Duchin (1986)). Without sufficient data on stocks of new technology equipment, the method used in MESIM, in which investment flows are extrapolated using time series methods but are also partly endogenous since they incorporate feedbacks from the MTC shock, represents a first step.

More detail with respect to the important international trade links associated with the MTC shock would be useful. Again, however, the flexibility afforded by the switch variable method used in MESIM gives some indication of the range of possible results. Finally, the fact

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[15]In other words, we are not distinguishing between shifts in the production function and movements along it as we track changes in the production points.

that MESIM is based on man-hours rather than man-years, not only allows the alternative reference paths discussed above concerning future trends (by sector) with respect to weekly working hours, but also provides considerable potential to incorporate issues such as work sharing.

4. RESULTS

The model (MESIM) produces annual results for each solution path: 19xx(R), 19xx(S), 19xx(F). For example: required labor force by sector and occupation; levels of the 18 endogenous aggregate demand and income variables (the former are disaggregated across the 39 sectors); intermediate inputs to production (39 by 39) plus gross and net outputs by sector. In addition, for the post-technical-change solution path 19xx(S), the model computes for each of the MTC applications: the potentially equipped work places; the actually equipped places (given the diffusion rate); and the number of displaced workers by application and by occupation.

Analysis of the results proceeds as follows. Data (such as, sectoral/occupational employment matrices) from the post-technical-change solution paths—19xx(S) and 19xx(F)—for a particular scenario (for example, (000)) are compared to those from the chosen reference path, and decomposed according to changes originating from the supply side (productivity and input changes) versus final demand changes. A comparison of the final path (19xx(F)) with the reference path (19xx(R)) isolates the structural adjustments (occupational and sectoral) required to reemploy the workers displaced by the microelectronic-based technical change, the latter having been computed along the 19xx(S) solution path.

Recall that the levels of the aggregate demand variables, for example GDP, will be approximately equal along the solution paths 19xx(R) and 19xx(S)—approximately because the structure will have changed somewhat—while the levels of the employment variables will be approximately equal along the solution paths 19xx(R) and 19xx(F). That is, after the technical progress the same level of output can be produced with fewer workers or more output can be produced using the reference path level of employment. MESIM was not designed to give predictions of the levels of the various variables in, for example, 1990 but rather to provide a *comparative* scenario analysis in a general equilibrium setting.[16] Nevertheless, the levels for the variables seem quite plausible.

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[16]The predictions concerning levels of the variables are subject to the difficulty that the input/

4A. Aggregate Employment and Income Effects of Alternative Scenarios

Table 1 illustrates the impact of microelectronic-based technical change under scenario (000) using four alternative reference paths. Reference path R-R incorporates the extrapolated historical rates of change for labor productivity ($1/Q$), materials input structure (A), the structure of final demand across sectors ($YSTR$), and sectoral weekly working hours (HW). This reference path corresponds to the revolutionary view of MTC since the effects of that new technology on Q and A are super-imposed on their historical trends. Keeping weekly working hours fixed at base-year levels rather than allowing them to continue their downward trend (reference path R-H) results in higher unemployment by 1990, as expected.

At the other extreme is the reference path R-B (which is often used in input-output modelling) for which the supply-side structure (Q,HW,A) and the structure of final demand across sectors ($YSTR$) is held fixed at base-year (1979) levels. This reference path is the counterfactual to the unlikely situation in which the MTC is the only source of increased labor productivity during the 1980s. A more interesting alternative to the R-R (revolutionary) view is that captured by the reference path R-E which corresponds to an evolutionary view in that MTC is a continuation of past trends of technical change. As mentioned above, this case is modelled by subsuming the impact of MTC on Q and A into the extrapolated historical rates of change. Table 1 reports that the R-E reference path unemployment rate is 9.7 percent in contrast to the revolutionary case which results in 12.2 percent. Under scenario (000), the impact of MTC is to increase the reference path unemployment rate by 3.2 percent to 12.9 (15.4) percent for R-E (R-R). However, when/if the appropriate structural adjustments take place, those displaced workers will be re-employed using the new technological/occupational structure resulting in a R-E (R-R) equilibrium unemployment rate of 9.2 (11.7) percent.

Tables 2 and 3 report results relative to reference path R-R. In particular, Table 2 reports the cumulative displacement of workers due to microelectronic-based technical change (MTC) by 1990 (that is, 1990(S)–1990(R) in percentage terms) for alternative scenarios relative

output data only captures part (essentially the commercial sector) of the economy in contrast to the national income and product accounts on which the demand structure is built. To handle this issue, we absorbed the difference into the hidden employment variable (EH) which is extrapolated as a fraction of the labor force and added back into the demand structure every year.

Table 1: Percentage Displacement of Workers for Scenario 000 Relative to Alternative Reference Paths[a]

	R-B		R-R		R-H		R-E	
	1990(R)		1990(R)		1990(R)		1990(R)	
TE	13260		12015		11578		12362	
RQLF	9857	–5.0	8612	–5.1	8175	–5.3	8959	–4.9
E	8671	–5.3	7677	–5.3	7292	–5.5	8003	–5.1
SE	1186	–2.9	935	–3.5	883	–3.6	956	–3.3
U	432		1677		2115		1330	
UR(R)	3.1		12.2		15.4		9.7	
UR(S)		6.7		15.4		18.6		12.9
UR(F)		2.4		11.7		15.0		9.2

[a]R-B ≡ reference path which keeps labor productivity (1/Q), interindustry inputs (*A*), allocation of demand across sectors (*YSTR*), and weekly working hours by sector (*HW*) constant at base-year (1979) levels. R-R ≡ reference path which allows *Q*, *A*, *YSTR*, and *HW* to evolve according to their historical rates of changes. R-H ≡ reference path which allows *Q*, *A*, and *YSTR* to evolve but keeps *HW* fixed at base-year levels. R-E ≡ reference path which allows *Q*, *A*, *YSTR*, and *HW* to evolve but subtracts the impact of MTC on *Q* and *A* from those trends so that the former are subsumed in the latter for post-technical-change paths. *TE* is total employment or *RQLF* + *EH* where *EH* is "hidden employment," that is, employment not captured by the input-output-based supply side of the model, *RQLF* is employment required by the latter, *E* is employees, *SE* is self-employed, *U* is unemployment, *UR*(*R*) is the unemployment rate for the reference path or counterfactual solution, *UR*(*S*) is that for the post-technical-change solution keeping demand at reference path levels, and *UR*(*F*) is the unemployment rate after displaced workers are reemployed using the new structure. Table items in the first three rows of columns 2, 4, 6, and 8 indicate percentage displacement according to scenario 000 (see key to Table 2) for different counterfactuals relative to their respective reference path levels (measured in thousands of man-years), that is, [(1990(S) – 1990(R))/1990(R)] × 100.

Table 2: Percentage Displacement of Workers for Some Alternative Scenarios Using Reference Path R-R[a]

Scenarios	000	001	010	100	101	110	111	210	211
RQLF	−5.1	−2.8	−6.2	−7.6	−5.4	−9.0	−6.8	−17.5	−15.4
E	−5.3	−3.1	−6.4	−7.9	−5.7	−9.3	−7.2	−18.1	−16.1
SE	−3.5	.9	−4.5	−5.1	−2.5	−6.5	−4.0	−12.4	− 9.8
UR(S)-UR(R)	3.2	1.8	3.9	4.8	3.4	5.7	4.3	11.	9.7
UR(F)-UR(R)	−0.5	−2.0	0.2	−0.7	−2.2	0.2	−1.2	−0.1	−1.6

[a]Scenarios indicated in column headings are labelled by the setting of the "switch" variables (*S*1, *S*2, *S*3) where:

*S*1 indicates the speed of diffusion:
- = 0 implies empirically observed and extrapolated rates.
- = 1 implies a 50% faster rate of diffusion.
- = 2 implies full implementation by 1990.

*S*2 indicates the fraction of new equipment which is imported:
- = 0 implies the same fraction imported as along the reference path.
- = 1 implies all microelectronic-based machinery and equipment is imported.

*S*3 indicates the level of exports:
- = 0 implies empirically observed.
- = 1 implies a shift (increase) in the export function by 5 percent.

See Table 1 for definitions of employment variables in the row headings. Table items in the first three rows are percentage displacement for various scenarios relative to their common reference path solution, that is, [(1990(S) − 1990 (R))/1990(R)] × 100.

Table 3: Percentage Change in Aggregate Variables for Some Alternative Scenarios[a]

Scenarios	000	001	010	100	101	110	111	210	211
GDP	7.3	9.7	6.1	11.1	13.7	9.3	11.8	22	24.9
CONS	8.2	10.7	7.1	12.6	15.1	10.8	13.4	25.6	28.5
VEST2	6.4	6.3	6.3	9.7	9.7	9.6	9.6	21.6	21.6
EX	7.6	15.4	6.5	11.6	19.7	9.9	17.8	23.2	32.2
IM	8.1	12.3	8.6	12.4	16.8	13.1	17.4	29.2	34.1
GOVD	2.9	–2.1	5.1	4.4	–1.0	7.6	2.5	14.7	8.8
WGH	7.2	8.7	6.5	11.0	12.5	9.8	11.4	22.8	24.6
PRGH	8.3	9.1	7.8	12.7	13.5	11.9	12.8	27.2	28.2

[a]See Table 2 for a key to scenario definitions. GDP is gross domestic product, *CONS* is private sector consumption, *VEST2* is machinery and equipment investment, *EX* is exports, *IM* is imports, GOVD is the government deficit, *WGH* is gross wages per employee hour, and *PRGH* is gross profits per self-employed hour. Table items are percentage changes for various scenarios relative to their common reference path solution, that is, [(1990(F) – 1990(R))/1990(R)] × 100.

to their common reference path R-R. For example, for scenario (010), 6.2 percent of the 1990 required labor force is displaced in the 1980s. If none of these workers are reemployed (for example, if final demand remains at reference path levels), then the unemployment rate would increase by 3.9 percent relative to the R-R reference path by 1990. Of course, some of these displaced workers are likely to be reemployed by 1990. Table 2 also reports the change in the unemployment rate, relative to the reference path solution, when all the displaced workers are reemployed according to the new technological/occupational structure. For example, for scenario (001) the 1990(F) rate converges to 10.2 percent (12.2–2.0).

With respect to comparative scenarios, since the changes are expressed for each scenario relative to a common reference path, the incremental effect of a different combination of switch variables can be calculated by taking the difference between the table elements. For example, in Table 2, the effect of MTC on the required number of employees (E) under scenario (110) relative to scenario (010) is an additional (cumulative) displacement of 2.9 percent ($9.3-6.4$) of employees by 1990. That is, increasing the rate of diffusion from empirically observed rates ($S1=0$) to a fifty percent faster rate ($S1=1$), when all the new technology equipment is imported ($S2=1$), results in a considerable increase in the number of displaced employees.

Clearly, the cumulative displacement of workers increases as the rate of diffusion of the new technology increases. However, from the viewpoint of output per employed worker, a faster rate of diffusion is a good thing. Table 3 illustrates some benefits of the technical progress by computing the increases in the aggregate levels of income and final demand made possible by the microelectronic-based technical change when all the structural adjustments have taken place—that is, all the displaced workers are reemployed according to the new technological/occupational structure and the general equilibrium solution 1990(F) is attained.

For example, according to scenario (000) the microelectronic-based technical change allows gross domestic product to be 7.3 percent higher by 1990 than it would be on the corresponding reference path (no MTC) solution. Similarly, gross wages (profits) per hour increase by 7.2 (8.3) percent. Comparing the impact of MTC under alternative scenarios, *WGH* (*PRGH*) increase by an additional 3.3 (4.1) percent in going from scenario (010) to scenario (110). Scenario (111) results in *WGH* and *PRGH* being respectively 11.4 and 12.8 percent higher than on the reference (no MTC) path. Changes in the government deficit (GOVD) across various scenarios are primarily due to changes

Table 4: Supply versus Demand Sources of Change for the Required Labor Force[a]

Reference path		$\hat{Q}$	($\hat{P}r$)	$\hat{A}$	$\hat{Y}$	inter	net
R-R	1990(R)-1979	−13.1	(1.2)	−0.6	26.7	−4.4	8.6
	1990(F)-1990(R)	− 6.2	(0.56)	−0.2	7.6	−0.5	0.7
	Total	−19.3	(1.76)	−0.8	34.3	−4.9	9.3
R-E	1990(R)-1979	− 7.6	(0.69)	−0.4	23.9	−3.0	12.9
	1990(F)-1990(R)	− 5.9	(0.54)	−0.2	7.2	−0.4	0.7
	Total	−13.5	(1.23)	−0.6	31.1	−3.4	13.6
R-B	1990(R)-1979	0	(0)	0	24.3	0	24.3
	1990(F)-1990(R)	− 6.2	(0.56)	−0.2	7.9	−0.5	1.0
	Total	− 6.2	(0.56)	−0.2	32.2	−0.5	25.3

[a]Key: See Table 1 for alternative reference path definitions and the key to (R), (S), and (F) solutions.

$\hat{Q}$ ≡ percent change in RQLF due to labor productivity changes.
$\hat{P}r$ ≡ average yearly labor productivity increase in percentage terms.
$\hat{A}$ ≡ percent change in RQLF due to non-labor input changes.
$\hat{Y}$ ≡ percent change in RQLF due to final demand changes.
inter ≡ percent change in RQLF due to 2nd and 3rd order interaction effects - such as $\hat{Q}*\hat{Y}$.
net ≡ $\hat{Q} + \hat{A} + \hat{Y}$ + inter.

in tax revenues as gross domestic product responds to changes in the structure and level of imports and exports, and to changes in unemployment insurance payments as the level of unemployment changes.

Finally, for three alternative reference paths, Table 4 decomposes the changes in the total required labor force into those originating from the supply side (labor productivity and material input changes) versus final demand changes. Table 4 also summarizes the labor productivity changes by reporting the average yearly labor productivity increases due to microelectronic-based technical change (1990(F) − 1990(R)), and due to other sources as captured by the chosen reference path (1990(R) − 1979).

The microelectronic-based technical change sources of increased labor productivity (0.56 percent per year) comprise approximately one-third of the total increase in labor productivity (1.76 percent per year) when reference path R-R is used (as in Tables 2 and 3), whereas MTC is the only source of increased labor productivity when the reference path keeps the supply structures fixed at base-year levels (as in R-B). The intermediate case (R-E) incorporates non-MTC sources of increased labor productivity (0.69 percent per year) to the extent that the total, *including* MTC, is 1.23 percent per year. The latter is approximately equal to the counterfactual (before MTC effects are superimposed) for the R-R case, which incorporates the extrapolated historical (1970s) rates of change (1.2 percent per year). That is, the R-R (revolutionary) case superimposes the MTC effects, whereas the R-E (evolutionary) case subsumes the MTC effects in the extrapolations of the 1970s rates of change. As is clear from Tables 1 and 4, the level of the 1990 unemployment rate is sensitive to one's view concerning the nature of the technical change (evolutionary or revolutionary) and the evolution of working hours. However, the impact of MTC on the number of workers displaced and on income, and the comparative scenario exercise (such as, increasing the rate of diffusion and increasing exports) are not changed substantially by one's choice of reference path.

4B. Some Occupational Implications

The results in this section focus on the occupational shifts required to accommodate the structural change, initiated by the microelectronic-based technical change, while maintaining employment at reference path levels—that is, reaching solution path 19xx(F). The structural shifts are decomposed into those changes originating on the supply side (changes in labor productivity ($1/Q$) and nonlabor inputs (A)), those due to final demand changes (Y), and those due to higher-order interaction effects.[17] This decomposition is somewhat analogous to the separation of occupational versus industry effects for historical periods in, for example, Gershuny (1983), Magun (1984), and Whitley and Wilson (1983).

The decomposition of the historical changes in the required labor force (RQLF) summarized in Table 5 shows that, in total, increases in labor productivity reduce the RQLF by 9.2 percent from 1971 to 1979.[18] Nevertheless, increases in demand offset the direct negative influence of technical change on the RQLF for all occupational groups except for those occupations related to the primary sector which decreased in absolute terms by 0.3 percent. However, when the scale (growth) effect (28.5 percent on average) is excluded—compare the first and last columns of Table 5—we see that the service-related occupations (groups I to V) all increased in relative terms, over the

[17]For example, those changes originating from $\hat{Q}*\hat{Y}$ which result from the method of decomposition.

[18]This is consistent with findings by Magun (1984) and Economic Council of Canada (1984).

Table 5: Percentage Change in Occupational Structure 1971–79[a]

Occupations	1971 RQLF as a percent of the total	$\hat{Q}$	$\hat{A}$	$\hat{Y}$	inter	net	1979 RQLF as a percent of the total
Managers and Administrators	4.3	26.4	8.7	45.4	12.0	92.5	6.4
Professionals	5.7	0.2	9.3	47.1	1.6	58.2	7.0
Clerical	17.4	− 7.8	6.5	45.6	− 4.8	39.5	18.9
Sales	13.7	−12.0	0.4	41.9	− 5.7	24.6	13.3
Services	9.1	− 1.7	2.3	42.2	− 1.7	41.1	10.0
Primary	10.8	−15.9	− 2.5	23.3	− 5.2	− 0.3	8.4
Processors	5.6	−11.3	0.4	36.2	− 6.3	19.0	5.2
Machinists	4.0	−19.4	− 1.3	44.2	−10.4	13.1	3.6
Fabricators, assemblers, repairers	10.5	−10.9	0.1	41.6	− 6.1	24.7	10.2
Construction, transport	14.2	−12.5	2.8	33.7	− 5.4	18.6	13.0
Equipment operatives, craftsmen	4.7	−23.3	3.1	40.6	−10.6	9.8	4.0
Total	100.0	− 9.2	2.5	39.5	− 4.3	28.5	100.0

[a]Key: $\hat{Q}\equiv$ percent change in RQLF due to labour productivity ($1/Q$) changes.
$\hat{A}\equiv$ percent change in RQLF due to non-labour input changes.
$\hat{Y}\equiv$ percent change in RQLF due to final demand changes.
inter≡ percent change in RQLF due to second and third order interaction effects - such as $\hat{Q}*\hat{Y}$.
net≡ $\hat{Q} + \hat{Y} + \hat{A}$ + inter.

Notice that the last column has been adjusted to exclude scale effects so that its elements sum to 100.

period 1971 to 1979, except for sales, which decreased slightly from 13.7 percent of the total in 1971 to 13.3 percent of the 1979 total. In contrast, the occupations related to manufacturing, construction, and transport operatives (groups VII to XI) all decreased in relative terms in the 1970s. Of course, because the primary sector occupations (group VI) decreased in absolute numbers, they also decreased in relative terms.

Table 6: Percentage Change in Occupational Structure for the Reference Path R-R (1979 – 1990(R))[a]

Occupation	1979 RQLF as a percent of the total	$\hat{Q}$	$\hat{A}$	$\hat{Y}$	inter	net	1990(R) RQLF as a percent of the total
Managers and administrators	6.4	−13.5	4.3	28.6	−4.7	14.7	6.8
Professionals	7.0	−15.7	7.4	30.7	−5.8	16.6	7.5
Clerical	18.9	−13.3	3.5	29	−5.2	14.0	19.9
Sales	13.3	− 6.6	−2.1	28	−2.4	16.9	14.4
Services	10.0	6.8	0.3	28.4	0.4	35.9	12.6
Primary	8.4	−25.7	−4.5	16.6	−4.1	−17.7	6.3
Processors	5.2	−23.5	−5.4	23.1	−5.8	−11.6	4.2
Machinists	3.6	−18.4	−7.7	28.4	−7.3	− 5.0	3.1
Fabricators, assemblers, repairers	10.2	−22.8	−3.3	26.7	−6.6	− 6.0	8.8
Construction, transport	13.0	− 9.4	−3.1	25.0	−4.2	8.3	12.8
Equipment operatives, craftsmen	4.0	−21.7	−2.5	26.8	−7.2	− 4.6	3.5
Total	100.0	−13.1	−0.6	26.7	−4.4	8.6	100.0

[a]Key: See Table 5. Changes are calculated according to [(1990(R) – 1979)/1979] × 100.

Table 6 continues the decomposition out-of-sample as predicted by the counterfactual (no MTC) reference path (1990(R-R) – 1979). Primary sector occupations continue to decline and secondary sector occupations (processors, machinists, fabricators/assemblers/repairers, equipment operatives/other craftsmen) now decline both in relative and absolute terms as opposed to only in relative terms as in the 1970s. Construction and transport operatives increase but decline very slightly in relative terms.

Labor productivity increases along this reference path at the (simple) average annual rate of 1.2 percent (using the 1990(R) technology, 1979 output could be produced with 13.1 percent fewer workers). The scale effect (on average 8.6 percent) is considerably smaller than that for the historical period. Although this reflects the (reference path) predicted increase in the unemployment rate from 7.4 (1979) to 12.2 (1990(R)) percent, and the slowdown in the job creation associated with the predicted decline in the growth of the labor force relative to that in the 1970s, the scale effect is also sensitive to the time path of EH (see footnote 16). Nevertheless, the model was designed primarily to analyse the implications of alternative scenarios and the relative shifts in occupations rather than levels and rates of growth. Also, as we saw in Table 1, using the evolutionary reference path (R-E) would result in more plausible *levels*.

Whereas Table 6 reports the cumulative effect of increased labor productivity, decreased material input requirements, and increased demand predicted by the counterfactual path from 1979 to 1990(R), Table 7 gives the impact of the MTC predicted by scenario (000). Therefore, adding Table 6 plus Table 7 gives the total occupational shifts for the 1980s predicted by the reference path R-R and scenario (000), resulting in occupational shares as reported in the final column of Table 7. According to this reference path and technical change scenario, the total increase in labor productivity is such that 19.3 percent fewer workers are required to produce a given amount of output with the 1990(F) technological/occupational structure as opposed to that in 1979. However, increases in demand are such at 34.4 percent more workers are required. Once all the interaction effects are included, the net effect is an average scale increase of 9.3 percent (compare Table 6 plus Table 7 with R-R in Table 4).

Finally, by comparing the occupational structure for the post-technical-change solution 1990(F) with that for the counterfactual (no MTC) solution 1990(R), Table 7 (in the last and first columns respectively) illustrates the occupational adjustments required to accommodate the MTC (reemploy the displaced workers). For example, for this scenario, professionals increase (from 7.5 to 8.4 percent of the total) while machinists decrease (from 3.1 to 2.2 percent of the total). Some occupations (for example, personal services and construction) increase not because they were directly affected by the technical change but rather because of the general increase in final demand made possible by the technical change. Therefore, relative to the reference path, the predicted impact of this MTC on the occupational structure reinforces the relative decrease of processors, machinists, fabricators/assemblers, and crafts/equipment operatives; reinforces the relative increase in professionals, sales, and personal service occupations; offsets the relative decrease in primary and construction trades/transport operatives; and offsets the relative increase in managers/administrators, and clerical occupations.

The reported results, of course, reflect the technical change data (*S*

Table 7: Percentage Change in Occupational Structure due to MTC for Scenario (000)[a]

Occupation	1990(R-R) RQLF as a percent of the total	$\hat{Q}$	$\hat{A}$	$\hat{Y}$	inter	net	1990(F) RQLF as a percent of the total
Managers and administrators	6.8	− 8.6	−0.2	7.6	−0.7	− 1.9	6.6
Professionals	7.5	4.4	−0.2	7.5	0.4	12.1	8.4
Clerical	19.9	−12.4	−0.2	7.7	−1.0	− 5.9	18.6
Sales	14.4	− 4.3	−0.1	7.9	−0.3	3.2	14.8
Services	12.6	− 0.4	−0.1	7.9	0	7.4	13.4
Primary	6.3	− 0.3	−0.1	7.6	0	7.2	6.7
Processors	4.2	− 9.1	−0.4	7.5	−0.7	− 2.7	4.1
Machinists	3.1	−34.4	−0.4	7.6	−2.5	−29.7	2.2
Fabricators, assemblers, repairers	8.8	− 9.7	−0.2	7.6	−0.7	− 3.0	8.5
Construction, transport	12.8	− 0.8	−0.2	7.1	−0.1	6.0	13.5
Equipment operatives, craftsmen	3.5	−10.4	−0.3	7.6	−0.8	− 3.9	3.4
Total	100.0	− 6.2	−0.2	7.6	−0.5	0.7	100.0

[a]Key: See Table 5. Changes calculated according to [(1990(F) − 1990(R))/1990(R)] × 100. Scenario (000) incorporates empirically observed and extrapolated diffusion rates for the new technology; the same fraction of new technology equipment imported as along the reference path; and empirically observed and extrapolated export function.

and *P*). The better this data is, the more accurate the results. This study is indebted to the Leontief and Duchin (1986) and the Bundesministerium (1981) studies which were the primary courses from which the *S* and *P* estimates were derived. The "engineering" nature of this data, and the fact that the impact of a microprocessor for the same industry in Canada versus the U.S. or Austria should be similar, allows considerable confidence in the results. As more data with respect to *S* and *P* by sector and occupation becomes available for Canada, it should be possible to refine the results. Of course, the rate of diffusion and the trade implications could be very different for Canada. For this reason we computed the implications of alternative scenarios with respect to those variables.

5. CONCLUDING COMMENTS

It is virtually impossible to predict the aggregate and structural implications of the pervasive technological and organizational changes which are likely to result from microelectronic-based technical change. However, it is possible to determine the probable upper and lower bounds of the feasible outcomes by simulating alternative general equilibrium scenarios. For example, uncertainty concerning our rate of adoption of the new technology (relative to other countries) is modelled above by comparing alternative scenarios determined by different diffusion rates, different degrees of dependence on foreign production of the required new equipment, and different degrees of success in export markets.

In addition, it is difficult to predict the speed and extent of the economy's response to the introduction of the new technology. Because the detailed information necessary for the appropriate use of more traditional approaches is unavailable, we have imposed less structure on the adjustment. First of all, the reference path incorporates detailed sectoral substitution trends for both supply and demand. Secondly, the range of feasible transition paths is derived (for each alternative scenario) by computing two post-technical-change paths—one which keeps output levels equal to those along the reference or counterfactual path so that the number of displaced workers can be computed, and the other which computes the final demand and income made possible when/if all the displaced workers are reemployed using the new technological/occupational structure.

Modelling the potential sources of occupational shifts out-of-sample provides an indication of the magnitude of possible structural unemployment (occupational and sectoral mismatches between layoffs and new job vacancies) initiated by structural changes such as microelectronic-based technical change. Again, a comparison of the implications of alternative scenarios allows a computation of the relative impact of different variables and shocks, and is a useful precursor to any policy analyses. For example, increasing the rate of diffusion of the new technology requires larger occupational shifts in order to prevent technological unemployment. The technical change modeled in this paper would accelerate historical trends by reinforcing both the relative decrease in manufacturing-related occupations and the relative increase in professionals, sales, and personal service occupations. However, MTC offsets the relative increase in managers/administrators and clerical occupations, and also offsets the relative decrease in construction/transportation operatives and primary sector occupational groups.

The aggregate results for a plausible scenario indicate that the microelectronic-based technical change modelled in this paper initiates a 0.5 percent average yearly increase in labor productivity and consequently results in a cumulative displacement of 5 to 6 percent of the (1990) required labor force from 1981 to 1990. Of course, when/if the appropriate structural adjustments take place, those workers will be reemployed and national income will improve correspondingly. An increase in Canada's rate of diffusion (especially vis-à-vis our trading partners) implies more initial displacement, but again the even higher productivity gains (plus the potential for export gains) should ultimately improve national welfare. This conclusion highlights the importance of facilitating the required structural adjustments.

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