D.G. McFETRIDGE

# Advanced Technologies in Canada: *An Analysis of Recent Evidence on Their Use*

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# Foreword

This is one of several studies commissioned by the Economic Council of Canada as part of a larger project on Competitiveness and Trade Performance. The project was designed to explore why Canadian industry has performed so poorly over the past 20 years and to compare Canada's performance with those of other industrial and newly industrialized nations. Studies show that Canada's position has been slipping relative to that of its trading partners, and that this jeopardizes future living standards. The project also provides valuable information about the feedback between the micro-world of management and labour and the macro-world of inflation and exchange rates. Its primary conclusion is that Canadians have not responded quickly or effectively enough to the challenges that have been taking place in international markets. The Council's findings were published in February, 1992 in a Statement titled *Pulling Together: Productivity, Innovation and Trade*.

Technological changes can improve overall productivity and real incomes of Canadians only if their effective use is widespread within and across industrial sectors. Professor McFetridge was asked to meet two objectives in this study: first, to determine the characteristics of firms associated with the use of advanced technologies in Canada; and, second, to compare the rate of adoption of advanced manufacturing technologies in selected industries in Canada and the United States. His results confirm the findings of a 1983 report by the Council (The Bottom Line) that the diffusion of technologies into and within Canada was slower than in the United States. Also, Canadian plants are less likely to use advanced technologies and, if they do, they tend to use fewer of them.

What is particularly disturbing, however, is that the United States itself is clearly slower than Japan and Germany in adopting advanced manufacturing technologies.

Because the Economic Council closed in June 1992, this study is being published by the Canada Communication Group.

Donald McFetridge is currently a member of the Department of Economics, Carleton University, Ottawa. He has written widely on economic and Canadian policy issues and is also well-known as an advisor to governments. I also wish to acknowledge the contributions of Statistics Canada and Industry, Science and Technology Canada to this study.

Judith Maxwell
Chairman
Economic Council of Canada

# Introduction

This study has two objectives. The first is to determine the characteristics of manufacturing establishments in Canada using advanced manufacturing technologies in order to determine whether there are barriers to the adoption of advanced manufacturing technologies that could be reduced by changes in public policy.

The second objective is to compare the respective penetration rates of advanced manufacturing technologies in selected industries in the United States and Canada in order to determine whether the use of advanced manufacturing technologies (AMTs) in Canada lags that in the United States and, if so, whether this can be traced to the characteristics of the industries or the technologies involved.

This study also makes use of two major sources of data. The first is Statistics Canada's 1989 Survey of Manufacturing Technology (henceforth, the AMT survey) which is used together with the annual Census of Manufactures to determine the respective characteristics of users and non-users of advanced manufacturing technologies. The Survey of Manufacturing Technology is described in Statistics Canada (1989a, 1989b, 1989c). The statistical analysis of the differences between the characteristics of manufacturing establishments that have, and those that have not, adopted AMTs is presented in the section titled Evidence on the Use of Advanced Technologies in Canada.The second major source of data is the 1988 survey of manufacturing technology in the United States (U.S. Department of Commerce, Bureau of the Census, 1989). While this survey is not comparable to the Canadian survey in its published form, Statistics Canada has been able to achieve comparability by reworking the results of its own survey and adjusting some of the published U.S. results. These comparable data are reported in Statistics Canada (1991). An analysis of these comparable data is presented in the final section of this study.

# Advanced Manufacturing Technologies

The term "advanced manufacturing technology" is applied to a variety of manufacturing technologies, some of which (numerically controlled machine tools and programmable controllers) have been in use for many years. In recent years the term has come to be associated with the application of microprocessors to production (computer numerical control, computer-assisted design, engineering and manufacturing) and with automated materials handling (programmable robots and automated retrieval systems). These are also known as flexible technologies.

The categories of technologies included in recent surveys of advanced manufacturing technology in Canada, the United States and Australia are summarized in Table 1.

# Evidence on the Use of Advanced Technologies in Canada

## Recent Canadian Advanced Technology Diffusion Studies

The most recent evidence on the use of advanced manufacturing technologies is Statistics Canada's *Survey of Manufacturing Technologies* (1989a). The most recent evidence on the use of advanced technologies in the service industries is contained in Statistics Canada's "Diffusion of Technology Survey in the Service Industries", the results of which are published in *Technologies and Services* (Supply and Services Canada, 1990).

Earlier surveys of advanced technology use include the Economic Council of Canada's *Working with Technology: A Survey of Automation in Canada* (Betcherman and McMullen, 1986) and *Survey of Manufacturing Technologies* (Statistics Canada, 1987).

The 1989 survey of manufacturing technology reveals that, depending on the technology, the percentage of establishments using advanced manufacturing technologies (AMTs) varies between 6 and 30 per cent, accounting for between 18 and 77 per cent of manufacturing shipments. These data are presented in Table 2.

The findings of the *Technologies and Services* report with respect to the use of advanced technologies in the service industries are summarized in Table 3. Some of the more common technologies and systems, such as personal computers, facsimile machines and computerized financial systems, are in use in

**Table 1**

**Advanced Manufacturing Technologies**

| Technology Class | Technology | Description |
|---|---|---|
| I | | **Design and Engineering** |
| | 1 | Computer aided design (CAD) and/or computer aided engineering (CAE) |
| | 2 | CAD output used to control manufacturing machines (CAD/CAM) |
| | 3 | Digital representation of CAD output used in procurement activities |
| II | | **Fabrication and Assembly** |
| | 4 | Flexible manufacturing cell(s) (FMC) or systems (FMS) |
| | 5 | NC/CNC machine(s) |
| | 6 | Materials working laser(s) |
| | 7 | Pick and place robot(s) |
| | 8 | Other robots |
| III | | **Automated Material Handling** |
| | 9 | Automated storage and retrieval system (AS/RS) |
| | 10 | Automated guided vehicle systems (AGVS) |
| IV | | **Automated Sensor-Based Inspection and/or Testing Equipment** |
| | 11 | Performed on incoming or in process materials |
| | 12 | Performed on final product |
| V | | **Communications and Control** |
| | 13 | Local area network for technical data |
| | 14 | Local area network for factory use |
| | 15 | Inter-company computer network linking plant to subcontractors, suppliers, and/or customers |
| | 16 | Programmable controller(s) |
| | 17 | Computer(s) used for control on the factory floor |

90 per cent of service establishments with 20 or more employees. The report concludes that technology adoption in the service industries has the following characteristics:

- Adoption rates are highest in the communications, wholesale trade, finance and insurance and business service industries and lowest in the accommodation, food and beverage, and retail trade industries.
- Adoption rates are higher in establishments with more than 200 employees than in establishments with fewer than 200 employees.
- Adoption rates are higher among foreign-owned businesses.
- Adoption rates are lower in the Prairie and Atlantic regions than elsewhere in Canada.

**Table 2**

**Use of Advanced Manufacturing Technologies Canada, 1989**

| | Percentage of Establishments Using at Least One Technology in the Class | Percentage of Shipments Accounted for by Establishments Using at Least One Technology in the Class |
|---|---|---|
| Design and Engineering | 19 | 52 |
| Fabrication and Assembly | 21 | 47 |
| Automated Materials Handling | 6 | 18 |
| Automated Testing Communications | 11 | 41 |
| Communications and Control | 30 | 77 |
| Manufacturing Information | 18 | 51 |
| Integration and Control | 9 | 40 |

Source Statistics Canada (1989a), Tables 3, 17

**Table 3**

**Service Sector Establishments Using or Planning to Use Selected Technologies**

| Technology | % Using | % Planning to Use Within 3 Years |
|---|---|---|
| **Office Automation** | | |
| Personal Computers | 89 | 3 |
| Online Terminals | 76 | 4 |
| Mini-Computers | 54 | 4 |
| Mainframe Computers | 41 | 2 |
| **Office Networking** | | |
| Facsimilie | 89 | 3 |
| Local Area Networks | 40 | 17 |
| Telex | 36 | 0 |
| Electronic Mail-Private | 30 | 14 |
| Wide Area Networks | 29 | 10 |
| External Databases | 22 | 8 |
| Mobile Data Communications | 11 | 5 |
| Electronic Mail-Public | 10 | 9 |
| Voice Mail | 6 | 7 |
| Satellite Data Distribution | 3 | 5 |
| Video Conferencing | 2 | 5 |
| **Design Support Systems** | | |
| Desktop Publishing | 30 | 15 |
| Computer-Aided Design | 14 | 5 |
| Computer-Aided Engineering | 6 | 4 |
| Computer-Aided Software Engineering | 6 | 8 |
| **Inventory/Sales Systems** | | |
| Computerized Inventory Control | 56 | 12 |
| Computerized Order Entry | 50 | 9 |
| Point of Sale Terminals | 22 | 8 |
| Electronic Data Interchange | 19 | 16 |
| Electronic Scanning Systems | 15 | 14 |
| Automatic Retrieval Systems | 10 | 4 |

Source: Industry, Science and Technology (1990), Table 2.2

## Evidence on the Factors Associated with Advanced Technology Adoption

The empirical literature on the factors associated with the adoption of new technologies concludes that the following firm or establishment characteristics have tended to contribute to early adoption:

- large scale
- a strong growth record
- organizational receptivity as manifested in management's education and interaction with suppliers.

In a Canadian context, location and ownership have also been factors with alocation in central Canada and foreign ownership tending to favour adoption.

The 1986 report of the Economic Council of Canada, *Working with Technology*, shows that the proportion of firms or organizations introducing computer-based automation between 1980 and 1985:

- tended to be lower than the national average in the Atlantic provinces and Quebec and higher in Western Canada
- increased with establishment size
- was greater among foreign-owned than among Canadian-owned firms
- was greater among U.S.-owned than among other foreign-owned establishments.

In a study of Quebec firms, Julien, Carrière and Hébert (1988) found that the adoption of NC/CNC machines in the plastics, machine shop and sawmilling industries is associated with firm size and the presence of a university-educated owner-manager. The following forms of behaviour were also observed:

- information gathering from suppliers and trade fairs
- conduct of market studies
- collaboration with outside research organizations
- use of a computer.

It is noteworthy that the behavioural correlates of adoption may be either causes or consequences of the adoption decision. In the view of Julien et al. the decision not to adopt a numerical control system is often the result of a failure to appreciate or cost-out the time saving aspect and/or the improvement in quality it can generate. Management education is, therefore, a factor here, as is the cost burden imposed on a small firm by a proper evaluation.

A study by the Department of Industry, Science and Technology (1990a) also emphasizes the importance of staff and managerial skills. The study notes that adopting firms must have sufficient internal technological competence to solve problems arising during the adoption process and that outside sources cannot be relied upon to solve every problem that arises.

More recently, Lefebvre, Harvey and Lefebvre (1991) have been able to distinguish between the factors associated with the *initial* adoption of advanced manufacturing technologies and the factors associated with their *continuing* adoption. Specifically, the authors analyze the factors associated with the adoption of *one* of: computer-assisted design, computer-assisted manufacturing, computer numerically controlled machine tools, automated storage and retrieval, and automated inspection and quality control; and the factors associated with the adoption of *more than one* of these technologies by 100 and 44 small Quebec manufacturing firms, respectively.

The authors interpret their results as implying that scale, financial condition, the desire to achieve cost savings and the influence of the CEO are associated with a firm's first step into computer-based manufacturing while customers, suppliers and the influence of professional personnel within the firm are associated with subsequent steps.

In another paper (Lefebvre, Lefebvre and Harvey, 1991a), the same authors find that the adoption of advanced computer-based manufacturing by 116 small, manufacturing firms in Quebec is associated with two factors — the technical capabilities of blue collar workers and the influence of suppliers and consultants — to the apparent exclusion of all others.

Of course, worker upgrading and interaction with suppliers and consultants are part of the technology adoption process rather than a cause of it. The key question for competitiveness is whether in Canada there are impediments to either skill acquisition or supplier interaction that do not exist in other industrial countries.[1]

## Modelling the Determinants of AMT Use

### *Specifying the Model*

The method of investigation employed in this study is to distinguish statistically between the characteristics of manufacturing establishments using various advanced technologies and the characteristics of establishments not using advanced technologies. In order to do this it was necessary to match the establishments covered in the 1989 AMT survey with the 1987 and 1982 Censuses of Manufactures. The 1987 census was the most recent available at the time this analysis was undertaken. Matching the AMT survey establishments with the 1982 census allows for the calculation of historic (5-year) growth rates for each establishment. After omitting some major groups, in which the use of advanced technologies is minimal, there are approximately 2200 establishments covered in the AMT survey for which 1987 and 1982 census data exist.

Logit analysis is then used to determine whether the characteristics of establishments using various AMTs as of 1989 differ statistically from the characteristics of establishments not using them. A recent paper by Dunne (1991) takes a similar approach using data from the United States. Dunne uses multivariate probit analysis to explain interestablishment differences in the use of AMTs in the United States. The U.S. AMT survey is described in the second part of the section titled Canadian Advanced Technology Usage in an International Context.

In the simplest terms the model is:

$$P_{ij} = f(X_i) \qquad (1)$$

where $P_{ij}$ = the probability that the ith establishment is a user of the jth technology as of 1989, and $X_i$ = a vector of characteristics of the ith establishment as revealed in the 1987 Census of Manufactures.

The existing theoretical and empirical literature on the determinants of technology adoption suggests that the following characteristics of the establishment should influence the probability of adopting new technologies:

- establishment scale
- domestic multi-establishment scale
- international multi-establishment scale
- past rate of growth in establishment output
- establishment age
- establishment location
- technological opportunity.

Establishment scale is generally regarded as the most important explanatory factor in empirical studies of technology adoption. Also, there are two sources of scale advantage in new technology adoption. The first is that some technologies are best suited to large scale use and are uneconomic for small plants. This scale bias may decline over time as a technology is adapted for smaller scale use.[2] In this case, successively smaller establishments should adopt a technology with the passage of time.

The second source of scale advantage is derived from the fixed costs of acquiring a new technology. These are the costs of evaluating alternative suppliers and of integrating the new technology with existing operations. Such costs might be termed "search and shakedown" costs.[3] They are fixed in the sense that they do not increase proportionately with the amount of the new technology purchased. Also, these fixed acquisition costs may decline over time relative to the purchase price of a new technology. This would occur if performance characteristics become more widely known and less uncertain over time. Acquisition becomes a matter of routine and the disadvantage of small scale acquisition is reduced. The relationship between the age of a technology and its adoption cost is explored in more detail below.

The existence of an establishment scale advantage that declines over time implies that users of AMTs should be larger than non-users. Establishments planning to use AMTs should be in between. As Table 4 indicates, this is generally the case. The relationship between adoption costs and the timing of adoption is further explored in Appendix A.

**Table 4**

**Average Scale* of Establishments by Technology Class and Category of Use**

| Technology Class | Used in Operations | Plan to Use | Not Cost Effective | Not Applicable |
|---|---|---|---|---|
| Design & Engineering | 57 | 89 | 46 | 56 |
| NC/CNC Machines | 140 | 104 | 49 | 71 |
| Fabrication & Assembly | 167 | 146 | 48 | 65 |
| Automated Materials Handling | 168 | 209 | 85 | 64 |
| Automated Sensor-Based Testing | 222 | 106 | 54 | 61 |
| Communications | 189 | 99 | 52 | 48 |
| Programmable Controllers | 209 | 80 | 55 | 52 |
| Computers for Factory Control | 243 | 108 | 51 | 54 |

* Scale measured in terms of average number of employees.

Source: Statistics Canada, special tabulation.

Fixed acquisition costs may be spread over a number of plants. The experience gained in selecting and installing a new technology in one plant may be applied to others. In such circumstances multiplant firms have an advantage over single plant firms in that they can apply search and shakedown, and perhaps integration, costs over a larger number of purchases. Moreover, this multiplant advantage can, in principle, be realized in either domestic or foreign plants, that is, in either domestic multiplant or multinational enterprises.

Given scale, the likelihood of adoption should increase with the rate of establishment growth. Expanding establishments have both the opportunity to adopt new technologies and the prospect of reaching the critical scale threshold if they are currently below it.[4] The influence of growth on the probability of adoption should be greater for technologies characterized by high fixed and sunk costs. In such cases replacement of an old technology is unlikely in a no-growth situation.

Newer establishments are also more likely to use AMTs. Indeed, the construction of a new establishment and the adoption of AMTs may well be part of the same investment decision. It may also be that newer establishments can more readily accommodate new technologies.[5]

Establishment location can also influence the probability of adopting AMTs. Geographically isolated users may have higher search and implementation costs. Other influences on the probability of adoption may also vary from location to location. These include factor prices and product mix.[6]

The probability that an establishment will be a user of an advanced manufacturing technology can also depend on technological opportunity. Although AMTs may be broadly applicable, some are more applicable, both in some major groups than in others and within major groups, in some three-digit industries than in others. There is no direct measure of inter-industry differences in technological opportunity, but this may be partly remedied by estimating models at the major group level. Differences across three-digit industries within major groups remain. One way of standardizing for differences in technological opportunity across three-digit industries is to use the percentage of using establishments each three-digit industry as an explanatory variable in the model. This practice is followed in this study.

## *Explanatory Variables*

The explanatory variables employed in this study are set out in Table 5. The first set measures establishment scale. There are two alternative measures: value added and employment. The employment scale measure is expressed both in continuous terms (as the natural logarithm of employment) and in discrete terms (as dummies equal to one if an establishment exceeds a certain scale). The size classes are chosen to match those used in the U.S. Census of Manufactures.

The second set of independent variables (VOPSI, NOPSI, VOM, NOM, VOPVOM, NOPNOM) is comprised of measures of domestic multiplant activity. Again, there are two alternative measures: employment and value added. Multiplant activity can be broken down into activity in the same three-digit industry and activity in other three-digit industries within manufacturing. It is reasonable to expect the advantage of multiplant scale to be greater if the plants involved are in the same three-digit industry than if they are in other manufacturing industries.

The foreign ownership dummy, DFO, intended to measure international multiplant scale advantages, is obviously an imperfect measure. For example, domestic firms may also have plants abroad; and foreign-owned firms may have no plants or many plants abroad and these plants may be in a variety of industries.

Establishment growth is measured over the five-year period 1982-87. While it would be preferable to measure growth up to 1989 (the year of the AMT Survey), 1987 is the last year for which census data are presently available. Growth is also measured in nominal terms. A measure of real growth would have been preferable but no establishment level deflators are available. The problem posed by using nominal growth rates can be avoided in part by estimating the model at the major group level. This eliminates the effect of differences in rates of product price change among major groups.

The establishment age measure (ALEQ15) is a dummy variable equal to one if the establishment is less than 15 years of age, zero otherwise. However, it may not be useful to distinguish between establishments over and under 15 years of age. Very few (fewer than ten in total) establishments included in the AMT Survey and matched to the Census are less than five years of age. Since the rate of growth could not be measured for these establishments (they entered after 1982), they were dropped. There are also relatively few establishments less than ten years of age. While a ten-year age dummy (ALEQ10) can be used when various major groups are pooled, there are generally not sufficient establishments under ten years of age in any individual major group to make an over ten/under ten distinction.

Nor is it possible to distinguish the very old establishments from the others. Establishments are identified by birth year on the census files only after 1972. There is no data on the age of establishments more than 15 years old.

Any four of the locational dummy variables can be used in the model. Regional representation is rather thin in some regions and industries. The results reported here make the distinction between central Canadian locations and the rest of the country.

Inter-industry differences in technological opportunity are measured by the percentage of establishments in the same three-digit industry which are using or planning to use a given technology or group of technologies.[7]

## *Dependent Variables*

The technologies covered in the AMT Survey are described briefly in Table 1. The results reported at present relate to the use or non-use of these technologies or groups of technologies. The first set of dependent variables is composed of 17 binary variables defined as:

$$\begin{aligned} D1VJ &= 1, J = 1 \ldots 17, \text{ if the Jth technology is being used,} \\ &= 0, \text{ otherwise.} \end{aligned}$$

Using the D1VJs as dependent variables implies the estimation of 17 equations for each major group. These estimates are not reported in this study (although they are available). The results reported here make use of a smaller set of dependent variables based on technology classes. These are defined as follows:

**Table 5**

**Explanatory Variables**

| | |
|---|---|
| LNN: | (Natural) logarithm of establishment employment. |
| LNV: | Logarithm of establishment value added. |
| DN1: | Dummy variable equal to one if establishment employment is between 100 and 250, zero otherwise. |
| DN2: | Dummy variable equal to one if establishment employment is between 250 and 500, zero otherwise. |
| DN3: | Dummy variable equal to one if establishment employment exceeds 500, zero otherwise. |
| VOPSI: | Value added of other establishments in the same three-digit industry under the same ownership (i. e., same unconsolidated enterprise). |
| NOPSI: | Employment of other establishments in the same three-digit industry under the same ownership (i. e., same unconsolidat ed enterprise) |
| VOM: | Value added of other establishments in other manufacturing industries under the same ownership (i. e., same consolidated enterprise). |
| NOM: | Employment of other establishments in other manufacturing industries under the same ownership (i. e., same consolidat ed enterprise). |
| VOPVOM: | VOPSI + VOM. |
| NOPNOM: | NOPSI + NOM. |
| DFO: | Dummy variable equal to one if the establishment is foreign-controlled, zero otherwise. |
| LNG: | Growth rate of establishment shipments 1982-1987. |
| ALEQ15: | Dummy variable equal to one if the establishment is less than fifteen years old, zero otherwise. |
| DR1: | Dummy variable equal to one if the establishment is located in the Atlantic region, zero otherwise. |
| DR2: | Dummy variable equal to one if the establishment is located in Quebec, zero otherwise. |
| DR3: | Dummy variable equal to one if the establishment is located in Ontario, zero otherwise. |
| DR4: | Dummy variable equal to one if the establishment is located in the prairie provinces, zero otherwise. |
| DR5: | Dummy variable equal to one if the establishment is located in British Columbia, zero otherwise. |
| ITE: | Percentage of establishments in the same three-digit industry which are using or planning to use a given technology. |

D2V1 = 1 if any of technologies 1. . . 3 (Design and Engineering) are used, zero otherwise.
D2V2 = 1 if technology 4 (FMC/FMS) is used, zero otherwise (D2V2 = DlV4).
D2V3 = 1 if technology 5 (NC/CNC Machines) is used, zero otherwise (D2V3 = DlV5).
D2V4 = 1 if any of technologies 4, 6, 7 or 8 (Fabrication and Assembly) are used, zero otherwise.
D2V5 = 1 if any of technologies 9 or 10 (Automated Materials Handling) are used, zero otherwise.
D2V6 = 1 if any of technologies 11 or 12 (Automated Sensor-Based Testing) are used, zero otherwise.
D2V7 = 1 if any one of technologies 13...15 (Communications) are used, zero otherwise.
D2V8 = 1 if technology 16 (Programmable Controllers) is used, zero otherwise (D2V8 = D1V16).
D2V9 = 1 if technology 17 (Computers for Factory Control) is used, zero otherwise (D2V9 = D1V17).

### *Functional Form and Estimation Method*

The logistic functional form is used in this study. This constrains the probability of use to lie along an S-shaped curve asymptotic to zero and one. Thus the statistical model is:

$$D2VJ_i = 1 / [1 + \exp(-b_k X_{ki})\ ],\ J = 1 \ldots 11 \qquad (2)$$

where the D2VJs are defined above (Dependent Variables) and the $X_{ki}$ are the K characteristics of the ith establishment as defined above (Explanatory Variables).

Model (2) is estimated for individual major groups and for various sets of major groups. These pooled estimates constrain some of the $b_k$ to equality across major groups.

Model (2) is also estimated for a subsample of establishments with 20 employees or more. This subsample is comparable to the U.S. AMT survey in terms of size of establishments covered. The results reported below in the part titled Determinants of AMT Use: Statistical Results, are obtained from this subsample.

The logit models are estimated by the maximum likelihood method using the SAS Logist routine. Estimates obtained using SAS were verified using the more familiar logit routine in SHAZAM.

**Table 6**

**Estimates of Model (2) for 12 Major Groups**

| | Independent Variable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technology Class | int | DR2 | DR3 | DFO | ALEQ15 | LNG | LNN | NOPNOM+ | IIE | MCS |
| Design and Engineering | - 4.97 | -.100 | -.165 | .051 | -.090 | .107 | .611*** | -.300** | 3.27*** | 350/10 |
| FMC/FMS | -5.21 | .448** | .187 | .249* | -.186 | .443*** | .318*** | -.106 | 6.39*** | 153/9 |
| NC/CNC Machines | -5.35 | .330** | .175** | .152 | -.245 | .133 | .497*** | -.277** | 5.14*** | 459/10 |
| Fabrication and Assembly[a] | -5.25 | .581*** | .298** | .138 | -.320 | .220*** | .431*** | -.168 | 4.01*** | 233/10 |
| Automated Material Handling | - 4.74 | .591*** | -.046 | .303* | .321 | .241* | .282*** | .149 | 3.27*** | 136/11 |
| Automated Sensor-Based Testing | -5.32 | .203 | -.263* | .143 | .147 | -.007 | .540*** | .091 | 4.26*** | 408/11 |
| Communications | - 4.94 | .306** | -.120 | .318*** | .062 | .009 | .606*** | .091 | 2.22*** | 345/9 |
| Programmable Controllers | -5.83 | -.001 | .019 | .190 | .060 | .191** | .738*** | -.048 | 3.77*** | 664/10 |
| Computers for Factory Control | -5.85 | .221 | -.025 | .194 | .268 | -.008 | .711*** | -.083 | 2.97*** | 419/10 |

+ All coefficients multiplied by $10^{-4}$

* Denotes significant at 10 per cent

** Denotes significant at 5 per cent

*** Denotes significant at 1 per cent

a Excludes NC/CNC machines, but includes FMC/FMS

**Table 7**

**Estimates of Model (2) for 12 Major Groups**

| | Independent Variable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technology Class | int | DR2 | DR3 | DFO | ALEQ15 | LNG | LNV | VOPVOM+ | IIE | MCS |
| Design and Engineering | -4.34 | -.094 | -.139 | -.099 | -.116 | .034 | .514*** | -.337*** | 3.56** | 364/11 |
| FMC/FMS | -4.75 | .483** | .222 | .161 | -.197 | .384*** | .258*** | -.090 | 6.38*** | 153/9 |
| NC/CNC Machines | -4.37 | .416** | .334** | .151 | -.289 | .036 | .336*** | -.255** | 5.10*** | 441/9 |
| Fabrication and Assembly[a] | -4.53 | .649*** | .330** | .129 | -.337* | .148 | .348*** | -.229* | 4.00*** | 230/10 |
| Automated Material Handling | -4.79 | .718*** | -.035 | .261 | .310 | .100 | .255*** | .170 | 3.44*** | 139/11 |
| Automated Sensor-Based Testing | -4.53 | .247 | -.182 | .057 | .094 | -.080 | .415*** | .116 | 4.30*** | 397/10 |
| Communications | -4.04 | .379*** | -.064 | .145 | .028 | -.100 | .521*** | .039 | 1.97*** | 348/9 |
| Programmable Controllers | -5.03 | .051 | .076 | -.007 | .035 | .059 | .657*** | -.084 | 3.71*** | 685/8 |
| Computers for Factory Control | -4.81 | .306** | .061 | .026 | .215 | -.145 | .587*** | -.110 | 2.70*** | 420/8 |

+ All coefficients multiplied by $10^{-4}$

* Denotes significant at 10 per cent

** Denotes significant at 5 per cent

*** Denotes significant at 1 per cent

a Excludes NC/CNC Machines but includes FMC/FMS

## Determinants of AMT Use: Statistical Results

### *Hypothesis Testing with Pooled Data on Twelve Major Groups*[8]

Pooled estimates of model (2) constrain the coefficients of the explanatory variables to equality across major groups. Intercept terms are allowed to differ. Estimates of model (2) are reported in Tables 6 and 7.[9] There is little to choose between employment and value added as scale measures. Both specifications yield similar results.

Establishment scale is positive and significant at 1 per cent for all technology classes. The elasticity of adoption with respect to establishment scale measured by employment is marginally higher than the elasticity of adoption with respect to value added. This may be because value added is influenced by inter-establishment differences in wage rates and profits which obscure scale differences to some degree.

The scale elasticity of adoption varies from 0.23 (Automated Materials Handling, FMC/FMS) to 0.53 (Computers for Factory Control).[10] The technologies with the lowest incidence of use also appear to have the lowest scale elasticities of adoption. However, this is contrary to expectation as the advantage of large scale is supposed to diminish as a technology becomes older and more widely used.

The effect of establishment scale on the probability of adoption is also illustrated in Table 8, which reports the predicted probability of adoption for various establishment employment size classes. These results are obtained by replacing the continuous scale variable LNN with discrete size class dummy variables, in model (2). The likelihood of use of advanced manufacturing technologies in an establishment with more than 500 employees ranges from under two times to four times higher than in an establishment with fewer than 100 employees. In some cases (Automated Materials Handling) the incidence of use does not appear to increase appreciably once the 100 employee threshold is reached. In others (NC/CNC Machines, Automated Sensor-Based Testing), increases in establishment scale beyond 500 employees are associated with a significantly higher incidence of use.

Domestic multi-establishment scale never has a positive effect on the incidence of adoption, regardless of how it is measured. Indeed, in the few instances in which it is statistically significant, it is the wrong sign (i. e., negative).

International multiplant scale, as reflected by the foreign ownership dummy, is not a factor either. It is significant at the 1 per cent level in the case of communications technologies, where it is positive.

The implication of these results is that there are scale advantages at the establishment level in advanced manufacturing technology adoption but no domestic or international multiplant advantages. The implications of this finding were discussed earlier in this section.

**Table 8**

**Predicted Probability of Use by Size of Establishment and Technology Class (12 Major Groups)**

| | Size Class (Employees) | | | |
|---|---|---|---|---|
| Technology Class | 20-100 | 100-250 | 250-500 | Over 500 |
| Design and Engineering | .24 | .39 | .56 | .61 |
| FMC/FMS | .07 | .11 | .13 | .16 |
| NC/CNC Machines | .13 | .23 | .25 | .35 |
| Fabrication and Assembly | .11 | .21 | .26 | .32 |
| Automated Material Handling | .06 | .10 | .09 | .11 |
| Automated Sensor-Based Testing | .08 | .20 | .22 | .32 |
| Communications | .18 | .32 | .43 | .52 |
| Programmable Controllers | .19 | .39 | .49 | .61 |
| Computers for Factory Control | .12 | .27 | .40 | .43 |

**Table 9**

**Elasticity of Probability of Adoption with Respect to Scale of Establishment (12 Major Groups)**

| Technology Class | Value Added | Employment |
|---|---|---|
| Design and Engineering | .32 | .38 |
| FMC/FMS | .23 | .28 |
| NC/CNC Machines | ? | .38 |
| Fabrication and Assembly | .28 | .34 |
| Automated Material Handling | .23 | .25 |
| Automated Sensor-Based Testing | .33 | .44 |
| Communications | .36 | .42 |
| Programmable Controllers | .42 | .47 |
| Computers for Factory Control | .44 | .53 |

Among the other independent variables, establishment age is never statistically significant, while the rate of growth of establishment shipments is occasionally significant and positive as expected. Growth is significant less frequently than is expected, given the findings of other investigators. Possible explanations may lie in the relatively short period over which growth is measured or in the use of nominal as opposed to real growth.

With respect to interprovincial differences in the incidence of use, establishments in Quebec and, somewhat less frequently, establishments in Ontario, appear more likely to be users of advanced manufacturing technologies than are establishments located in the Atlantic or western portions of the country.

The percentage of establishments in the three-digit industry to which the ith establishment is assigned which are using or planning to use a technology is always a significant determinant of establishment use. This may reflect both inter-industry differences in technical opportunity and other three-digit industry characteristics such as openness to trade.

## *Hypothesis Testing with Four Major Groups Comparable to Those Included in the U.S. Survey*

The U.S. survey covers five major groups: Metal Fabricating, Non-electrical Machinery, Transportation Equipment, Electrical and Electronic Equipment, and Scientific Instruments. The first four are roughly comparable to Canadian major groups.[11]

Model (2) was estimated for the four Canadian major groups which have counterparts in the U.S. survey. Both pooled and individual major group estimates were obtained. This section reports on the pooled estimates, which are presented in Tables 10 and 11. The intercept shift dummies are not reported. These results are comparable in some respects with those of Dunne (1991).

The only consistently significant explanatory variables are establishment scale and the percentage of users or planned users in the same three-digit industry. Employment fits the data marginally better than value added as a scale variable. The scale elasticity of adoption does not appear to vary widely across technologies (see Table 12).

Multi-establishment scale is never statistically significant regardless of how it is measured. The same is true of establishment shipments growth. Establishment age is significant with the wrong sign in one case.

The results obtained in this study are similar to those of Dunne (1991) in two respects and different in another. Dunne finds that the probability of adoption is an increasing function of plant scale but is generally not a function of age. Dunne finds that the probility of adoption is generally higher among establishments owned by multi-plant firms.[12]

Foreign ownership has a positive effect on adoption in one case (at the 5 per cent level) and a negative effect in another (at the 10 per cent level).

**Table 10**

**Estimates of Model (2) for Four Major Groups**

| | Independent Variable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technology Class | int | DR2 | DR3 | DFO | ALEQ15 | LNG | LNN | NOPNOM+ | IIE | MCS |
| Design and Engineering | -5.99 | -.034 | -.278 | -.282 | -.175 | .096 | .715*** | -.118 | 4.46*** | 158/8 |
| FMC/FMS | -6.44 | .802** | .492 | .293 | -.450 | .231 | .410*** | -.111 | 5.35*** | 72/10 |
| NC/CNC Machines | -5.86 | .420 | .205 | -.084 | -.537 | .070 | .660*** | .094 | 5.06*** | 182/9 |
| Fabrication and Assembly[a] | -7.05 | .714** | .449** | .154 | -1.00** | .053 | .582*** | -.051 | 5.11*** | 154/10 |
| Automated Material Handling | -6.63 | 1.12** | -.282 | 1.14*** | .570 | .284* | .380** | .025 | 2.37* | 36/9 |
| Automated Sensor-Based Testing | -5.47 | .220 | -.205 | .076 | -.624 | .023 | .484*** | .257 | 5.45*** | 153/9 |
| Communications | -6.28 | -.427 | -.303 | .208 | -.277 | .085 | .802*** | -.081 | 3.13*** | 162/9 |
| Programmable Controllers | -5.52 | .269 | .443** | .228 | -.300 | .218 | .615*** | .106 | 3.30*** | 172/8 |
| Computers for Factory Control | -5.33 | -.169 | .235 | .134 | -.525 | .079 | .559*** | -.198 | 3.12 | 119/8 |

+ All coefficients multiplied by $10^{-4}$

* Denotes significant at 10 per cent

** Denotes significant at 5 per cent

*** Denotes significant at 1 per cent

a Excludes NC/CNC Machines but includes FMC/FMS

**Table 11**

**Estimates of Model (2) for Four Major Groups**

| | Independent Variable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technology Class | int | DR2 | DR3 | DFO | ALEQ15 | LNG | LNV | VOPVOM+ | IIE | MCS |
| Design and Engineering | -5.07 | .035 | -.239 | -.370* | -.191 | -.066 | .593*** | -.164 | 4.56*** | 155/8 |
| FMC/FMS | -4.36 | .820* | .608 | .197 | -.621 | .122 | .181* | -.103 | 4.76*** | 58/8 |
| NC/CNC Machines | -4.88 | .471* | .233 | -.135 | -.559* | -.056 | .527*** | .109 | 5.14*** | 174/9 |
| Fabrication and Assembly[a] | -5.09 | .747** | .528** | .058 | -1.09 | -.091 | .384*** | -.142 | 4.65*** | 138/8 |
| Automated Material Handling | -5.40 | 1.13** | -.167 | .942** | .437 | .142* | .273* | .026 | 1.97 | 32/8 |
| Automated Sensor-Based Testing | -4.66 | .302 | -.137 | .076 | -.606 | -.072 | .364*** | .237 | 5.52*** | 147/9 |
| Communications | -4.87 | -.383 | -.276 | .051 | -.309 | -.077 | .723*** | -.198 | 2.58*** | 162/9 |
| Programmable Controllers | -4.91 | -.301 | .416* | .124 | -.265 | .084 | .598*** | .062 | 3.21*** | 178/8 |
| Computers for Factory Control | -4.54 | -.119 | .245 | .088 | -.521 | -.018 | .458*** | -.246 | 3.25*** | 113/8 |

\+ All coefficients multiplied by $10^{-4}$

* Denotes significant at 10 per cent

** Denotes significant at 5 per cent

*** Denotes significant at 1 per cent

a Excludes NC/CNC Machines but includes FMC/FMS

Establishments located in Quebec have a higher probability of adoption (at the 5 per cent level) than Atlantic and Western Canadian establishments in three cases. Ontario establishments have a higher probability of adoption than Atlantic and Western Canadian establishments in one case.

**Table 12**

**Elasticity of Probability of Adoption with Respect to Scale of Establishment (Four Major Groups)**

| Technology Class | Value Added | Employment |
|---|---|---|
| Design and Engineering | 0.32 | 0.37 |
| FMC/FMS | 0.16 | 0.36 |
| NC/CNC Machines | 0.32 | 0.39 |
| Fabrication and Assembly | 0.29 | 0.45 |
| Automated Material Handling | 0.26 | 0.36 |
| Automated Sensor-Based Testing | 0.29 | 0.39 |
| Communications | 0.48 | 0.53 |
| Programmable Controllers | 0.40 | 0.40 |
| Computers for Factory Control | 0.34 | 0.42 |

## *Hypothesis Testing with Selected Major Groups*

Estimates of model (2) for Major Group 25 are reported in Table 13. The results are similar to the pooled results. Establishment scale is significant (at 5 per cent or better) with the correct sign in eight of nine cases. This is true of establishment growth in one case and establishment age in two cases. None of the Ontario regional dummy, the Quebec regional dummy or the domestic multi-establishment scale variable (NOM) is ever significant at 5 per cent. The foreign ownership dummy is significant and positive in two cases while the percentage of establishments in the same three-digit industry using the technology is significant and positive in five cases.

Estimates of model (2) for the Metal Fabricating major group are reported in Table 14. The model could not be estimated for Automated Materials Handling as there were too few establishments using this technology. Of the eight technology classes for which the model could be estimated, seven involve a scale effect and a three-digit industry effect which is significant at 5 per cent. Growth, age, and Ontario and Quebec locations are each significant on one occasion.

**Table 13**

**Estimates of Model (2) for Major Group 25: Wood Industries**

| | Independent Variable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technology Class | int | DR2 | DR3 | DFO | ALEQ15 | LNG | LNN | NOPNOM+ | IIE | MCS |
| Design and Engineering | -5.14 | -.108 | -.361 | .412 | -.467 | .352 | .617*** | -.158 | 2.77 | 27/8 |
| FMC/FMS | -6.70 | .532 | -.020 | .713 | -1.30 | .748** | .566*** | -.055 | 8.02** | 37/8 |
| NC/CNC Machines | -7.01 | .122 | .470 | .003 | -.322 | .272 | .729*** | -.325 | 8.88** | 22/8 |
| Fabrication and Assembly[a] | -6.38 | .259 | -.085 | .225 | -1.29** | .549* | .749*** | -.096 | 3.32 | 40/10 |
| Automated Material Handling | -5.96 | .593 | -.331 | 1.10** | -.080 | .349 | .551* | .350 | 3.21 | 25/8 |
| Automated Sensor-Based Testing | -7.76 | -.172 | -.752 | .921** | 1.36*** | .158 | .847*** | .061 | 5.97 | 80/8 |
| Communications | -7.71 | .469 | -.874* | .512 | .496 | .440 | .838*** | .405 | 3.73* | 67/8 |
| Programmable Controllers | -8.83 | -.561 | -.109 | .632 | .777* | .329 | 1.27*** | .137 | 4.46*** | 150/8 |
| Computers for Factory Control | -9.43 | .340 | -.879* | -.123 | 1.00** | -.024 | 1.29*** | .018 | 5.06*** | 97/8 |

\+ All coefficients multiplied by $10^{-4}$

* Denotes significant at 10 per cent

** Denotes significant at 5 per cent

*** Denotes significant at 1 per cent

a Excludes NC/CNC Machines but includes FMC/FMS

**Table 14**

**Estimates of Model (2) for Major Group 30: Metal Fabricating**

| | Independent Variable | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technology Class | int | DR2 | DR3 | DFO | ALEQ15 | LNG | LNN | NOPNOM+ | IIE | MCS |
| Design and Engineering | -4.98 | -.182 | -.053 | .094 | .828 | .225 | .511*** | -1.97 | 3.68*** | 39/8 |
| FMC/FMS | -5.56 | .917 | -.378 | .492 | -.152 | .556 | .484** | .464 | 5.28*** | 28/8 |
| NC/CNC Machines | -4.95 | 1.28*** | .369 | .092 | .378 | -.099 | .445 | .712 | 4.45*** | 40/8 |
| Fabrication and Assembly[a] | -5.80 | .971* | .054 | .369 | -.696 | .516 | .552*** | .548 | 3.65** | 37/8 |
| Automated Material Handling | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Automated Sensor-Based Testing | -4.74 | .301 | -.194 | .337 | .180 | -.109 | .319 | .403 | 5.29*** | 12/8 |
| Communications | -4.47 | -.377 | -.185 | .133 | .047 | -.000 | .633*** | .664 | 0.69 | 21/8 |
| Programmable Controllers | -6.82 | .889 | .793** | .370 | 1.19** | .507 | .774*** | .229 | 3.58** | 56/8 |
| Computers for Factory Control | -6.18 | .383 | -.067 | .237 | -.204 | .741** | .615*** | .437 | 4.31*** | 35/8 |

\+ All coefficients multiplied by $10^{-4}$

* Denotes significant at 10 per cent

** Denotes significant at 5 per cent

*** Denotes significant at 1 per cent

a Excludes NC/CNC Machines but includes FMC/FMS

## Implications of the Statistical Analysis of the Canadian AMT Survey

The statistical results obtained here imply that the incidence of the use of AMTs increases with establishment scale but is unaffected by increases in domestic or international multiplant scale. This could imply, first, that the fixed acquisition (search and shakedown) costs associated with these technologies are plant-specific. Hence there is no technology adoption spillover.

Second, fixed adoption costs could be relatively large and not plant-specific but, for some reason, this does not constitute a disadvantage to single establishment firms. In this case there must be alternatives to multiplant ownership as a means of economizing on search and shakedown and integration costs.

There are a number of possibilities here. Single plant firms may obtain the required guidance either from equipment suppliers, engineering consultants or non-profit technology centres, or by directly observing the equipment choices and run-in practices of multiplant firms.

In sum, the results obtained here imply either that there are no multiplant economies of technology adoption or that multiplant ownership is not necessary to realize them. The public policy implications of these alternative conclusions are quite different. The absence of interplant spillover effects implies that there is no demonstration effect, and this, in turn, implies that one form of positive externality commonly associated with technology adoption is not important. Thus these results provide no support for one of the common efficiency-based arguments for subsidizing technology adoption. There may, of course, be other efficiency-based arguments for measures encouraging new technology adoption. This is discussed later in this study in the part on Canadian Advanced Technology Usage in an International Context.

The second possibility is that there is a demonstration effect, but that the transferable learning involved is available to single establishment firms. If appropriate compensation is paid there is, again, no efficiency rationale for intervention. If single establishment firms free-ride there is an externality.

In this event there is a rationale for public support of advanced technology adoption but there is no basis upon which to determine the appropriate level of support. Whether the support currently provided by the favourable tax treatment and subsidization of R&D expenditures made pursuant to adoption (plus the advisory services of the NRC and provincial research councils) is sufficient remains unknown. One means of providing some information on the existence and magnitude of the adoption externality might be to ask respondents to the next AMT survey what sources of information they relied on when choosing, installing and running-in the AMTs they have acquired.[13]

The establishment scale effect may be due either to the existence of fixed establishment-specific acquisition costs or to indivisibilities in the technologies themselves, or to both. Both the degree of technological indivisibility and the relative magnitude of acquisition costs should decline over time. It should also be the case that, other things being equal, older technologies have lower scale elasticities of adoption than newer ones. There is clearly no simple relationship between technology age and the scale elasticity of adoption. This issue is explored in greater detail in the next section of this study.

Accepting that the establishment scale effect reflects the existence of indivisibilities of some sort, the question of policy implications arises. There are a number of important considerations here. First, although small establishments may not use AMTs in-house, they may benefit from AMTs by contracting out. Second, small establishments not using AMTs directly or indirectly may be operating in market segments where they are not economic.

Concern is more properly focsssed on establishments operating in segments of the market where in-house use of AMTs is advantageous but which are themselves too small for adoption to be economic. Of course adoption can be made privately economic by various subsidy schemes and assistance plans. This would not, however, contribute to economic efficiency.

If Canadian establishments are too small to justify the adoption of the AMTs being used in-house by their competitors abroad, one policy remedy is establishment rationalization. It has long been held that one of the consequences of trade liberalization would be establishments which resembled their international competitors more closely in terms of scale and specialization. This should not be taken to imply that rationalization is a sufficient remedy. Indeed, the results presented in the last section show that it is not.

The results presented here have some rough implications for the degree of rationalization that is required to overcome indivisibilities in AMTs themselves and in their acquisition costs. Of course further rationalization may be required to exploit fully all the economies offered by AMTs as well as those derived from other sources.

The smallest and largest size class dummy variables that are statistically significant in the pooled estimates (12 major groups) of model (2) are reported in Table 15. For all of the technology classes involved at least some of the advantages of large establishment scale can be realized at scales of as few as 100 employees. The threshold might turn out to be lower than this. Size class boundaries were chosen to match published U.S. census data. There were no experiments with alternative boundaries.

Perhaps more important is the result reported above in Table 8 that in five of nine cases the scale effect becomes statistically insignificant before the largest size class is reached. It may thus be the case that, from a technology adoption perspective, the amount of rationalization required to overcome the indivisibilities involved may be relatively modest.

In addition to their implications regarding the existence of a multiplant scale effect, the findings with regard to foreign ownership also have implications for the literature on multinationals and technology transfer. That literature has established that multinationals have an advantage in transferring new product and process technologies. This does not appear to involve an observable advantage in the acquisition of advanced manufacturing technologies

The findings regarding establishment location can be viewed on either a descriptive level or a theoretical level. On a descriptive level they imply that given establishment scale, growth and industry, overall differences in the incidence of use of AMTs between Ontario and the Atlantic and Ontario and the West are relatively minor. In a number of cases Quebec tends to have a higher incidence of use of AMTs than the rest of the country.

**Table 15**

**Smallest and Largest Statistically Significant Size Class Dummies by Technology Class (12 Major Groups)**

| Technology Class | Smallest Significant* Size Class | Largest Significant Size Class |
|---|---|---|
| Design & Engineering | $100 \leq N < 250$ | $250 \leq N < 500$ |
| FMC/FMS | $100 \leq N < 250$ | $100 \leq N < 250$ |
| NC/CNC Machines | $100 \leq N < 250$ | $N \geq 500$ |
| Fabrication & Assembly | $100 \leq N < 250$ | $100 \leq N < 250$ |
| Automated Material Handling | $100 \leq N < 250$ | $100 \leq N < 250$ |
| Automated Sensor-Based Testing | $100 \leq N < 250$ | $N \geq 500$ |
| Communications | $100 \leq N < 250$ | $N \geq 500$ |
| Programmable Controllers | $100 \leq N < 250$ | $N \geq 500$ |
| Computers for Factory Control | $100 \leq N < 250$ | $250 \leq N < 500$ |

*At the 5 per cent significance level.

Source: Statistics Canada (1991)

This raises the theoretical question of why Quebec might differ from the other regions. It could, of course, be some peculiarity of the mix of establishments in Quebec which is not reflected by the other explanatory variables. It could also reflect some difference in the administration of and/or response to the AMT Survey.

The difference might also have an economic explanation in that it could stem from factor price differences, although this seems unlikely. It could also reflect a greater effectiveness of various federal and provincial industrial assistance programs operating in Quebec. Again, this seems unlikely as the Quebec advantage does not hold for all technologies and, although it holds on average across industries, it does not hold in each industry.

While their underlying cause may be a matter of speculation, these results do not support arguments to the effect that Quebec establishments are systematically disadvantaged, by language for example, when it comes to AMT acquisition.

## Suggestions for Improving the Model

The results presented above should be regarded as preliminary. A number of improvements are possible. First, it is now possible to link the AMT survey to the 1989 census of manufactures rather than the 1987 census used here. Establishment characteristics would then be measured as they were when the AMT survey was taken, rather than two years prior to the survey. This is especially important for measuring the establishment growth rate which is the five-year growth rate *as of two years prior to the AMT survey* in this study.

Second, it may be possible to increase the representation of newer establishments in the matched sample. Newer establishments are not well represented in this study and this may have affected the statistical results.

Third, some of the independent variables could be defined differently. The rate of growth in nominal shipments could be replaced with the rate of growth in market share. This would be closer to a a real growth rate. At the same time, the percentage of establishments in the same three-digit industry that are using a given technology could be replaced with a three-digit dummy.[14] While this would increase the number of independent variables considerably, it would reduce any bias of the type described in endnote seven.

The dependent variable could also be defined in other ways. The model employed in this study distinguishes only between users and non-users. It does not distinguish between threshold users and intensive users or between threshold users and extensive (i.e. multi-technology) users. On reflection, the failure of most plant characteristics to differ between users and non-users is understandable given that the users group includes plants that make even the most limited use of a technology. The distinction between threshold and intensive users may be more interesting. Lefebvre *et al.* (1991) make a distinction of this nature when they compare the characteristics of first and second generation AMT adopters. Jang and Norsworthy (1992) do something similar in their multivariate analysis of the determinants of interplant differences in the *number* of AMTs used in the United States.

The findings of Jang and Norsworthy illustrate the limitations of the user/non-user distinction employed in this study. These authors find, first, that the *number* of AMTs used increases with plant scale, with the scale effect being most pronounced in the largest size class. In contrast, the effect of plant scale on the *probability of being a user* is frequently exhausted by the time the largest size class is reached (see Table 15).

Second, Jang and Norsworthy find that, among plants with more than 100 employees, the number of AMTs used in plants owned by multiplant firms is greater than the number of AMTs used in plants owned by single plant firms. In contrast, this study finds that multiplant operation does not affect the probability that a particular plant is a user.

Third, Jang and Norsworthy find that the number of AMTs used by foreign-owned plants (in the United States) is greater than the number used by domestically-owned plants. This difference narrows as plant scale increases. This study finds that ownership does not affect the probability that a particular plant is a user.

The Jang and Norsworthy results have some interesting but not entirely consistent implications. They imply that there are multiplant economies of *intensive* (as opposed to marginal) AMT use. These economies should be most important to the smallest plants but Jang and Norsworthy find the opposite. International multiplant economies of *intensive* (as opposed to marginal) AMT use also appear to exist and these are most prominent for the smallest plants, as might be expected. Caution is warranted when attributing the entire ownership effect to international multiplant economies. U.S.-owned plants may be owned by U.S.-based multinationals. If this were the case for all U.S.-owned plants (which is highly unlikely), then foreign ownership must be associated with other sources of advantage. One factor would be growth. The authors do not standardize for differences in growth rates and foreign investment may have been proportionately greater in the faster growing lines of business. Another factor would be the firm-specific advantage in production management frequently attributed to Japanese and German firms.

# Canadian Advanced Technology Usage in an International Context

## Existing Evidence

Historically, the perception has been that both diffusion of new technologies to Canada from abroad and diffusion of new technologies from firm to firm within Canada are relatively slow by international standards. This conclusion is embodied in the 1983 report of the Economic Council of Canada, *The Bottom Line: Trade, Technology and Economic Growth:*

> *Our general finding is that new technology diffuses slowly into Canada from other countries. It also diffuses slowly from firm to firm and region to region within the country. By new technology we mean new and improved products, processes and structures. Although there are some exceptions, case studies show that often the process of diffusion of technical change into and throughout Canada occurs more slowly than in other western developed nations and not only in the manufacturing sector but in the service sector as well. (p. 61)*

Others have qualified these conclusions. While first Canadian adoption of new technologies generally lags world first adoption, this lag has historically been no longer than that experienced by other industrial countries. Canada's relatively early position in the transfer order has been a result of both its proximity to the United States and the role of multinationals, which are relatively prominent in Canada in technology transfer (McFetridge and Corvari, 1985, and McFetridge, 1986). The Canadian position in the international transfer order of U.S. technologies has also tended to decline over time. This, together with the increasing importance of European and Japanese industrial technologies, may mean that, on average, first Canadian adoption now occurs later than first adoption in countries that compete with Canada.

With respect to domestic diffusion of new technologies, the conclusion that the process is slower in Canada than elsewhere is based on relatively few case studies which have not been able to distinguish slow domestic diffusion from a late start or low equilibrium penetration. In the simplest terms, lower Canadian use of a new technology may imply either slow adjustment or that the technology is of limited relevance in Canada.

These issues are revisited in the light of new evidence on the relative use of advanced technologies in the United States and Canada. This discussion appears later in this section.

## Comparison of AMT Usage Rates in Canada and the U.S.: Data Sources

The 1988 U.S. AMT Survey covers five U.S. major groups. These are:

| U.S. Major Group | U.S. SIC Code | Canadian SIC Code |
|---|---|---|
| Metal Fabrication | 34 | 30 |
| Industrial Machinery | 35 | 31 |
| Electric and Electronic Equipment | 36 | 33 |
| Transportation Equipment | 37 | 32 |
| Instruments and Related Products | 38 | -- |

The U.S. survey is confined to establishments of 20 employees or more. It is stratified with the proportion of the population sampled varying across strata. Estimates of population usage rates are derived by weighting the sample responses according to the inverse of the proportion of each establishment's stratum which is surveyed. The United States thus reports an establishment weighted percentage of users (planners, etc.) by major group.

There are two Canadian surveys. The 1987 AMT survey covers (roughly) establishments with 20 employees or more. It is stratified with sampling proportions differing among strata. The reported results are not weighted. As a result the stratum with the largest sampling proportions (the large establishment stratum) may be over-represented. For this reason Statistics Canada does not regard the 1987 Canadian and 1988 U.S. surveys as being comparable.

The 1989 Canadian survey covers all establishments. It is stratified, and sampled establishments are assigned the appropriate weights. Published results of this survey (Statistics Canada, 1989a, 1989b, 1989c) are not comparable to the U.S. survey for three reasons. First, the Canadian survey covers establishments with fewer than 20 employees while the U.S. survey does not. Second, U.S. and Canadian major group definitions do not match precisely; there is no Canadian major group equivalent to the U.S. Instruments and Related Products industry, but the other four U.S. major groups have rough Canadian equivalents. Third, the U.S. survey classes nonrespondents as non-users while the Canadian survey omits them. As a result U.S. usage rates are understated relative to Canadian rates.

This lack of comparability has led Statistics Canada to rework the results of its 1989 survey. This involves the elimination of establishments with fewer than 20 employees and shifting some Canadian three-digit industries around so that the three-digit composition of Canadian major groups more closely resembles that used in the United States. There are limits to the latter exercise, however. Sampling is random within size classes and major groups; three-digit industries are not necessarily representative; shifting a given three-digit industry to another major group may make both major groups non-representative.

Statistics Canada has derived estimates of the incidence of use of AMTs in Canada among establishments with 20 or more employees and for five "reconstructed" major groups which are intended to resemble their U.S. counterparts. Statistics Canada has also adjusted published U.S. usage rates to reflect Canadian treatment of nonrespondents. That is, for comparison with Canada, AMT usage in the United States is expressed as a fraction of responding establishments rather than sampled establishments. A comparison of reconstructed Canadian AMT usage rates with adjusted U.S. AMT usage rates was published by Statistics Canada (1991). Analysis of the pattern of differences in respective usage rates appears in the three parts following.

## Comparison of Canadian and U.S. AMT Usage: Statistical Results

Summary statistics for the responses to the Canadian and U.S. AMT surveys are reported in Table 16. The means in the Table are calculated for 17 technologies and five major groups and are unweighted.

The average percentage of establishments using AMTs is more than five percentage points lower in Canada than in the United States. The average percentage of establishments planning to use AMTs is more than three percentage points lower in Canada.

The average percentage of establishments regarding AMTs as not applicable in their operations is almost 14 percentage points higher in Canada than in the U.S. Conversely, the average percentage of establishments regarding AMTs as not cost effective and not using them for that reason is six percentage points lower in Canada than in the United States.

Results of tests of the hypothesis that the average percentage of establishments falling into each response category does not differ between the United States and Canada are reported in Table 17. The difference between the average percentage of establishments in Canada and the average percentage of establishments in the U.S. using AMTs is statistically less than zero. The average percentage difference between the percentage of using establishments in Canada and the percentage of using establishments in the United States is also statistically less than zero.[15]

Establishments in the United States are much more inclined than Canadian establishments to cite non-cost-effectiveness as a reason for not using AMTs. Canadian non-users are much more likely to cite non-applicability as their reason than are U.S. non-users. This is contrary to expectations and may reflect differences in the administration of the surveys in the two countries.[16]

The difference in the average percentage of using establishments in each country can be broken down by major group or by technology class or both. There are not enough observations in each technology class in each major group (sometimes only two) to test for statistical differences between the

**Table 16**

**Responses to Canadian and American AMT Surveys Summary Statistics (percentages)**

| | Canada | | | U.S. | | |
|---|---|---|---|---|---|---|
| Response Category | Mean | Median | Standard Deviation | Mean | Median | Standard Deviation |
| Used in Operations | 12.7 | 10.1 | 10.8 | 18.2 | 14.4 | 13.6 |
| Planning to Use Within Five Years | 11.8 | 10.0 | 6.4 | 15.1 | 14.0 | 6.1 |
| Not Applicable | 55.2 | 56.4 | 12.0 | 41.4 | 41.6 | 9.8 |
| Not Cost Effective | 11.6 | 11.1 | 6.0 | 17.5 | 15.3 | 7.4 |
| Other Non-use | 8.7 | 8.3 | 2.8 | 6.7 | 7.0 | 1.7 |
| Total | 100.0 | | | 99.0* | | |

* There remains in the U.S. data a residual of 1 per cent of non-respondents. If these are also removed from the sample, the remaining categories should be scaled up by the factor $(.99)^{-1}$. This makes the U.S./Canada gap marginally larger.

Source: Calculated from data provided by Statistics Canada, 1991

**Table 17**

**Test Statistics for the Difference of Two Means**

| Response Category | Canada-U.S. | Standard Deviation | t-value |
|---|---|---|---|
| Used in Operations | -5.6 | 0.6 | -9.52 |
| Plan to Use Within Five Years | -3.3 | 0.5 | -7.05 |
| Used or Plan to Use Within Five Years | -8.9 | 0.7 | -12.48 |
| Not Applicable | 13.8 | 0.9 | 15.60 |
| Not Cost Effective | -5.9 | 0.7 | -8.55 |
| Not Applicable or Not Cost Effective | -5.9 | 0.7 | -11.45 |

Source: Statistics Canada (1991)

United States and Canada within both individual technology classes and major groups.

Table 18 illustrates, in all five major groups for which data are available, the average percentage of establishments using AMTs is lower in Canada than in the United States. The percentage differences in the percentage of users are similar across major groups, with the exception of Metal Fabricating, in which the Canadian disadvantage is somewhat smaller.

**Table 18**

**Average Percentage of Using Establishments by Major Group**

| Major Group | Canada | U.S. | Mean Difference Canada-U.S. | Mean Percentage Difference |
|---|---|---|---|---|
| Metal Fabricating | 9.1 | 13.2 | - 4.1* | - 27.6* |
| Machinery | 14.0 | 18.3 | - 4.3* | - 46.5* |
| Transportation Equipment | 12.0 | 19.4 | -7.4* | -54.1* |
| Electrical and Electronic Equipment | 15.2 | 21.5 | - 6.3* | - 46.2* |
| Instruments and Related Products | 13.1 | 18.7 | - 5.6* | - 43.5* |

* Statistically significant at the 5 per cent level.
Source: Statistics Canada (1991)

The differences in the average percentage of establishments using AMTs by technology class are reported in Table 19. The percentage of using establishments is lower in Canada in all technology classes. In percentage terms, the gap is widest in the Fabrication and Assembly technologies (flexible manufacturing, lasers, robots) and Automated Materials Handling and narrowest in Design and Engineering (CAD/CAE) and communications (local and wide area networks).

## The United States/Canada Comparison in a Broader Perspective

The clear implication of the comparison of U.S. and Canadian AMT use presented in the previous section is that the percentage of using establishments is significantly lower in Canada than in the United States. The tenor of recent

**Table 19**

**Average Percentage of Using Establishments by Technology Class**

| Question Numbers on Questionnaire | Technology or Technology Class | Canada | U.S. | Mean Difference Canada-U.S. | Mean Percentage Difference |
|---|---|---|---|---|---|
| 1. . . 3 | Design and Engineering | 19.1 | 24.8 | -5.7* | -33.1* |
| 5 | NC/CNC Machines | 27.9 | 42.2 | -14.3* | -46.6* |
| 4, 6. . . 8 | Fabrication and Assembly | 5.2 | 8.4 | -3.2* | -56.9* |
| 9 - 10 | Automated Materials Handling | 1.6 | 3.0 | -1.4 | -55.6 |
| 11 - 12 | Automated Testing | 9.5 | 13.8 | -4.3* | -35.7* |
| 13. . . 15 | Communications | 14.6 | 19.8 | -5.2* | -33.2* |
| 16 | Programmable Controllers | 24.0 | 35.5 | -11.5* | -38.6* |
| 17 | Computers for Factory Control | 19.6 | 31.2 | -11.6* | -46.3* |

* Statistically significant at the 5 per cent level.
Source: Statistics Canada (1991)

U.S. discussions of technology diffusion in that country is that the U.S. lags Germany and perhaps Japan in the use of AMTs.[17] Thus, Canadian adoption lags that of a country which does not regard itself as having a particularly good record.

A summary of the respective NC/CNC machine adoption records of Germany, the United States and Canada is presented in Table 20. Canadian adoption rates are well below the United States (however measured) and Germany. As noted above, the U.S. AMT survey classifies non-respondents and out of frame respondents as non-users. If these are eliminated from the sample the percentage of using establishments necessarily rises. As a result, the United States compares more favourably with Germany, lagging the latter only in the largest size class.

The respective rates of usage of industrial robots among large firms in the United States and Japan have been estimated by Mansfield (1989). He finds that the percentage of large firms using robots in 1985 was generally higher in the United States in the sectors he examines (1989, Table 4). He also finds, however, that Japanese firms make much more extensive use of robots than do

**Table 20**

**Percentage of Establishments Using NC/CNC Machines in Five Size Classes: Canada (1989), United States (1988), Germany (1986)**

| Establishment Size (Employees) | Canada | United States: Comparable to Canada | United States: As Published | Germany |
|---|---|---|---|---|
| Under 20 | 7 | NA | NA | 15.8 |
| 20-99 | 21 | 39 | 35.9 | 36.0 |
| 100-499 | 42 | 54 | 50.0 | 55.9 |
| 500 and over | 65 | 73 | 69.8 | 87.3 |

Source: U.S. Congress, Office of Technological Assessment and Forecast (1990), Table 6-1; Statistics Canada

**Table 21**

**Percentage of Canadian and U.S. Establishments Using Programmable Multifunction Robots**

| Industry | Canada | United States |
|---|---|---|
| Fabricated Metal Products | 3 | 5 |
| Machinery and Equipment | 3 | 6 |
| Electrical and Electronic Equipment | 4 | 8 |
| Transportation Equipment | 7 | 12 |
| Instruments and Related Products | 5 | 5 |

Source: Statistics Canada (1991), Tables 15-19

American firms; that is, the intra-firm rate of diffusion is higher in Japan (1989, pp. 189-91). Mansfield attributes most of this difference to the willingness of Japanese firms to accept lower rates of return on their investments in robots than U.S. firms.

The percentage of Canadian manufacturing establishments using robots of the type examined by Mansfield is generally lower than in the United States. This is illustrated in Table 21. While a gap of the same magnitude need not necessarily exist among larger firms, these results indicate that Canadian industrial robot use would compare with Japan less favourably than with the United States.

The diffusion of automation among establishments with 10 or more employees within the Italian metal working sector has been investigated by Cainarca, Colombo and Mariotti (1989). The metal working sector appears to correspond roughly with the major groups covered in the Canada-United States comparison presented above.[18] The three surveys also cover some similar technologies or technology classes. These are NC machine tools, programmable robots, pick and place robots and computer-aided design/manufacturing (CAD/CAM). Italian use of the first three of these technologies as of 1985 compares favourably with U.S. use as of 1988 which, in turn, exceeds 1989 Canadian use. Italian use of CAD/CAM appears to be miniscule relative to both U.S. and Canadian use. Indeed, the difference is so large as to call into question the similarity of the respective definitions of CAD/CAM employed in Italy and North America. The details of this comparison are reported in Table 22.

**Table 22**

**Comparison of the Use of Selected Advanced Manufacturing Technologies in Canada (1989), United States (1988) and Italy (1985)**

| Technology | Country | | |
|---|---|---|---|
| | Canada | United States | Italy |
| | | (percentage of using establishments) | |
| NC Machine Tools | 27 | 45 | 51 |
| Pick and Place Robots | 5 | 8 | 8 |
| Programmable Robots | 4 | 6 | 8 |
| CAD/CAM | 12 | 18 | 1 |

Sources: Statistics Canada (1991), Table 17; Cainarca, Colombo and Mariotti (1989), Table 1 (rounded to the nearest percent).

Australia conducted an AMT survey in 1988 (Australian Bureau of Statistics, 1989). It covers manufacturing establishments with ten employees or more. Results are reported by major group or aggregations of major groups. Two major groups in the Australian survey are roughly similar in composition to the Canadian major groups used in the Canada-U.S. comparison. These are the Fabricated Metal Products and Transportation Equipment industries respectively.

**Table 23**

**Average Percentage of Establishments Using AMTs by Major Group and Technology Class: Australia (1988) and Canada (1989)**

| | | Mean Percentage of Users | |
|---|---|---|---|
| Major Group | | Australia | Canada |
| Fabricated Metal Products | | 3.4 | 9.1 |
| Transportation Equipment | | 8.2 | 12.0 |
| Question Number | Technology Class | | |
| 1...3 | Design and Engineering | 8.3 | 13.5 |
| 5 | NC/CNC Machines | 20.0 | 21.7 |
| 4, 6...8 | Fabrication & Assembly | 3.1 | 4.8 |
| 9 - 10 | Automated Materials Handling | 0.5 | 2.5 |
| 11 - 12 | Automated Testing | 3.3 | 8.7 |
| 13...15 | Communications | 4.8 | 12.1 |
| 16 | Programmable Controllers | 11.5 | 21.9 |
| 17 | Computers for Factory Control | 7.5 | 17.1 |

Source: Statistics Canada (1991), Australian Bureau of Statistics (1989)

The average percentages of establishments using AMTs in Australia and Canada respectively are reported for the two similar major groups (averaged over 17 technologies) and for eight technology classes (averaged over the number of technologies in the class and two major groups) in Table 23. Given that the Australian survey covers establishments with 10 or more employees while the Canadian results are for establishments with 20 or more employees, the percentage of using establishments might be expected to be higher in Canada. Indeed, it is markedly higher, except in the case of NC/CNC machines where the two countries have similar usage rates.[19]

## Sources of Canada/U.S. Differences in Adoption Rates

There are a number of possible explanations for the observed differences in the percentage of Canadian and U.S. establishments using AMTs. The most likely explanation is that Canadian establishments tend to be smaller than

**Table 24**

**Scale-Adjusted Percentage of Using Establishments in Canada**

| **Industry or Technology Category** | **Mean Percentage of Users** | |
|---|---|---|
| Major Group | Scale Adjusted | Unadjusted |
| Metal Fabricating | 9.5 | 9.1 |
| Machinery | 15.3 | 14.0 |
| Transportation Equipment | 15.4 | 12.0 |
| Electrical and Electronic Equipment | 16.9 | 15.2 |
| Instruments and Related Products | 16.5 | 13.1 |
| **Technology Class** | | |
| Design and Engineering | 21.1 | 19.0 |
| NC/CNC Machines | 30.6 | 27.9 |
| Fabrication and Assembly | 7.0 | 5.2 |
| Automated Materials Handling | 2.1 | 1.6 |
| Automated Testing | 11.3 | 9.5 |
| Communications | 17.0 | 14.6 |
| Programmable Controllers | 28.1 | 24.0 |
| Computers for Factory Control | 22.2 | 19.6 |
| **Total** | 14.7 | 12.7 |

Source: Statistics Canada, Special Tabulations and Tables 18 and 29

those in the United States, making AMT adoption less economic in Canada. The importance of establishment scale in explaining the incidence of AMT use has been documented earlier in this section. Smaller establishments are less likely to be AMT users.

Statistics Canada has calculated what Canadian AMT adoption rates would be if each of the five Canadian major groups used in this comparison had the same establishment size composition as their U.S. counterparts. The resulting scale-adjusted adoption rates are reported in Table 24.

The scale-adjusted percentage of AMT users is two percentage points higher than the unadjusted or raw percentage of users. Even after adjusting for scale, however, the percentage of AMT users in Canada lies below the United States. The average difference is 3.54 percentage points and it is statistically significant. Absolute and percentage differences between the percentage of AMT users in Canada and the United States are presented in Tables 24 and 25. These tables indicate that the adoption gap between the United States and

**Table 25**

**Scale-Corrected Differences in the Percentage of Using Establishments by Major Group**

| Major Group | Mean Difference Canada-U.S. | Mean Percentage Difference |
|---|---|---|
| Metal Fabricating | -3.7* | -22.9 |
| Machinery | -3.0* | -31.5* |
| Transportation Equipment | -4.0* | -26.2* |
| Electrical and Electronic Equipment | -4.7* | -32.0* |
| Instruments and Related Products | -2.2 | -13.8 |

* Statistically significant at the 5 per cent level.
Source: Tables 18 and 24

**Table 26**

**Scale-Corrected Differences in the Percentage of Using Establishments by Technology Class**

| Question No. on Questionnaire | Technology or Technology Class | Mean Difference Canada-U.S. | Mean Percentage Difference |
|---|---|---|---|
| 1 . . 3 | Design and Engineering | -3.7* | -22.9* |
| 4, 6. . . 8 | Fabrication and Assembly | -1.4 | -26.8* |
| 5 | NC/CNC Machines | -11.7* | -36.6* |
| 9 - 10 | Automated Materials Handling | -0.9 | -32.4 |
| 11 - 12 | Automated Testing | -2.5 | -19.1* |
| 13. . . 15 | Communications | -2.8* | -18.4* |
| 16 | Programmable Controllers | -7.4* | -23.4* |
| 17 | Computers for Factory Control | -9.0* | -35.1* |

* Statistically significant at the 5 per cent level.
Source: Tables 19 and 24

Canada persists, within at least some establishment size classes, in all the major groups covered and in all technology classes.

Notice that the elimination of the scale effect had the largest impact on the adoption gap in the Transportation Equipment industry. In this case the percentage difference in the percentage of users is reduced by half.

There is an adoption gap within at least some size classes (see Tables 25 and 26). It may not be common to all size classes and this is obviously relevant to the explanation of the underlying source of the adoption gap. Statistics Canada has been able to make one Canada-U.S. comparison within establishment size classes and major groups. This is reported in Table 27.

**Table 27**

**Percentage of Establishments Using at Least One Technology**

| | Employment Size Class | | | | | |
|---|---|---|---|---|---|---|
| | 20 - 99 | | 100-499 | | 500 or More | |
| Major Group | Can. | U.S. | Can. | U.S. | Can. | U.S. |
| Metal Fabricating | 43 | 57 | 79 | 87 | 99 | 97 |
| Machinery | 67 | 76 | 92 | 94 | 99 | 99 |
| Electrical and Electronic Equipment | 60 | 72 | 87 | 89 | 94 | 98 |
| Transportation Equipment | 41 | 52 | 68 | 84 | 97 | 98 |
| Instruments and Related Products | 43 | 69 | 93 | 89 | 99 | 99 |

Source: Statistics Canada (1991)

Table 27 compares the respective percentages of Canadian and U.S. establishments using at least one AMT by size class and major group. It is apparent that the difference in the likelihood of using any AMTs is largely confined to the 20-99 employee establishment size class. Of course, larger Canadian establishments may use fewer AMTs or use a given AMT less extensively in their operations than their U.S. counterparts. The United States did not publish information on the frequency with which two, three or more AMTs are used on a major group and establishment size basis. Neither survey provides any information in intra-establishment diffusion of individual AMTs.

There are a number of reasons why measured Canadian and U.S. AMT adoption rates differ within establishment size classes and major groups. One explanation is that the mix of industries differs between the two countries within major groups. For example, the Transportation Equipment major group is comprised of a number of industries including aircraft and parts, automobiles and parts, truck bodies, shipbuilding, boat building and railway rolling stock manufacturing. Some of these industries are more frequent users of AMTs than others. If the industries which are relatively frequent users account for a larger fraction of the Transportation Equipment major group in the United States than in Canada, then the measure of percentage of users at the major group level will be higher in the United States, even if the percentage of users in the component industries is the same in the two countries.

**Table 28**

**The Effect of Adjusting for Industry Mix Differences on the Use of AMTs in the Transportation Equipment Major Group**

| Technology (Question Number)* | U.S. % Users | U.S. % Users with Canadian Industry Weights | Canada-U.S. % Differences with no Adjustments | Canada-U.S. % Differences with Scale and Adjustment |
|---|---|---|---|---|
| 1 | 43.9 | 42.2 | -47.0 | -20.3 |
| 2 | 18.3 | 18.1 | -51.5 | -29.8 |
| 3 | 11.0 | 10.9 | -66.7 | -33.4 |
| 4 | 13.8 | 12.0 | -55.6 | -19.4 |
| 5 | 41.0 | 39.8 | -44.0 | -32.7 |
| 6 | 6.6 | 6.2 | -138.5 | -95.8 |
| 7 | 11.4 | 9.6 | -65.1 | -10.2 |
| 8 | 11.6 | 10.2 | -44.2 | 18.3 |
| 9 | 5.2 | 5.0 | -56.8 | -21.9 |
| 10 | 3.6 | 3.3 | 57.1 | -16.8 |
| 11 | 13.9 | 12.7 | -28.8 | 7.2 |
| 12 | 15.9 | 14.7 | -30.4 | 0.8 |
| 13 | 24.2 | 22.6 | -45.1 | -11.3 |
| 14 | 20.6 | 19.4 | -50.5 | -20.7 |
| 15 | 23.8 | 21.0 | -51.9 | -2.2 |
| 16 | 35.2 | 32.1 | -44.0 | -10.4 |
| 17 | 30.1 | 27.3 | -37.9 | -13.8 |
| **Average** | 19.4 | 18.1 | -53.8 | -18.4 |

* The technologies are described in Table 1

The preferred method of eliminating this problem is to compare AMT use in the two countries at the (three-digit) industry level. Unfortunately, Statistics Canada does not regard the establishments in its AMT survey as sufficiently accurate at the three-digit level for purposes of this type of comparison.[20] In order to obtain some sense of the importance of the industry mix effect, U.S. use of AMTs is recalculated for one major group (Transportation Equipment) on the assumption that the mix of three-digit industries in this major group is the same as in Canada.

The results of this calculation are summarized in Table 28, where it may be seen that the use of AMTs in the U.S. Transportation Equipment major group would be between .1 and 3.1 percentage points lower if it had the same industry composition as the Canadian Transportation Equipment major group. The reason for this result is that manufacturers of railway rolling stock are relatively more important in the Canadian Transportation Equipment major group as are boat and shipbuilding. The aircraft and motor vehicle and parts industries are correspondingly less important.[21] The boat and shipbuilding industry is a much less frequent user of AMTs than the motor vehicle and parts industry. If the U.S. Transportation Equipment major group had the same three-digit industry composition as its Canadian counterpart (ie., more boat and shipbuilding and fewer motor vehicles and parts), its use of AMTs would be reduced by an average of 1.3 percentage points.

Table 28 also shows that adjusting for both scale and industry mix differences results in a marked reduction in the adoption gap between the two countries. The average percentage difference in use falls from 54 to 18 per cent (see n. 15 for the definition of the percentage difference in use). Note, however, that this is likely an over-correction for differences in scale and industry mix in that some industries may be more frequent users because they contain a greater proportion of large plants.

A related explanation for observed differences in AMT use in Canada and the United States is that defence contractors are more likely to use AMTs than firms oriented strictly to commercial production, and there are proportionately more establishments engaged in defence production in the United States than in Canada. As Table 29 indicates, U.S. establishments manufacturing products to military specifications are more likely to use AMTs than U.S. establishments not manufacturing to military specifications. This difference is especially prominent in the case of NC/CNC machines. Some 58 per cent of plants manufacturing to military specifications use NC/CNC machines while only 37 per cent of plants not manufacturing to military specifications are users.

The percentage difference between Canadian and U.S. non-military adoption rates is smaller (less negative) than the percentage difference between Canadian and aggregate U.S. adoption rates. In the case of NC/CNC machines the percentage differences are 50 and 31 respectively.[22] Note, however, that comparing Canadian use with U.S. nonmilitary use over-compensates for the difference in the respective proportions of establishments engaged in defence production in the two countries in that considerable defence production does occur in Canada.

**Table 29**

**Effect of Type of Customer and Type of Production on the Use of AMTs in the United States**

**Percentage of Using Establishments**
**Five Major Group Weighted* Average**

| Technology (Question Number) | Canada | U.S. | U.S. Military | U.S. Non Military | U.S. Fabrication | U.S. Assembly |
|---|---|---|---|---|---|---|
| 1 | 34 | 42 | 49 | 39 | 31 | 50 |
| 2 | 12 | 18 | 25 | 14 | 22 | 11 |
| 3 | 6 | 11 | 14 | 9 | 10 | 14 |
| 4 | 9 | 12 | 15 | 9 | 10 | 12 |
| 5 | 27 | 45 | 58 | 37 | 54 | 15 |
| 6 | 2 | 5 | 9 | 3 | 4 | 11 |
| 7 | 5 | 8 | 7 | 8 | 4 | 6 |
| 8 | 4 | 6 | 7 | 6 | 4 | 6 |
| 9 | 2 | 3 | 5 | 3 | 1 | 5 |
| 10 | 2 | 2 | 2 | 1 | 1 | 2 |
| 11 | 7 | 11 | 16 | 7 | 9 | 13 |
| 12 | 10 | 14 | 19 | 10 | 12 | 18 |
| 13 | 15 | 21 | 25 | 18 | 14 | 27 |
| 14 | 11 | 18 | 22 | 18 | 12 | 23 |
| 15 | 11 | 16 | 18 | 16 | 15 | 19 |
| 16 | 23 | 35 | 42 | 31 | 32 | 31 |
| 17 | 17 | 30 | 37 | 26 | 25 | 33 |
| **Average** | 12 | 17 | 21 | 15 | 15 | 17 |

* This is the pooled average usage rate. It is the same as a weighted average because it allows the major groups with the larger number of establishments to have a greater weight.

Establishments within a given major group or industry may be specialized or at least oriented to a particular stage of production. The various stages of production may differ in their respective abilities to make use of AMTs, as shown in the final two columns of Table 29. The use of NC/CNC machines is more than three times greater among U.S. establishments engaged in fabrication than among U.S. establishments engaged in assembly. It may be the case that Canadian establishments in a given major group (or industry) are specialized to assembly while U.S. establishments are more likely to be engaged in fabrication. This would be another explanation for the marked difference in NC/CNC machine use between the two countries.

This stage of production explanation does not generalize to most other technologies. Most other technologies tend to be used more by establishments engaged in assembly than by establishments engaged in fabrication. If Canadian establishments were generally more oriented to assembly than U.S. establishments, their AMT use would be higher (other things being equal). If it is to be general, the stage of production explanation would have to be recast as Canadian establishments perform fewer of the functions that make intensive use of AMTs than do U.S. establishments. There is no evidence that this is the case.

To summarize, part of the gap between U.S. and Canadian AMT usage rates is attributable to differences in the two countries' respective scales of manufacturing establishments. A considerable gap remains, however, to be attributed to other factors. One is industry mix. Industries most likely to use AMTs are more important in the United States than in Canada. Within industries, establishments can differ with respect to the nature of their customers and their stage of production. Production to military specifications is more likely in the United States than in Canada, and fabrication may be more important relative to assembly in the United States than in Canada. The use of AMTs tends to be greater among establishments producing to military specifications. The use of *some* AMTs is greater among establishments engaged primarily in fabrication.

## Interpretation of Observed Canada/U.S. Differences in AMT Use

Taken as a whole, the results reported above imply that Canadian manufacturing establishments are less likely to be making use of advanced technologies than U.S. establishments. This adoption gap exists in each of the five major groups surveyed and in each technology class. The adoption gap is clearly apparent in the smallest size class of establishments surveyed (20 to 99 employees). It may or may not exist in the larger size classes. Within size classes, some of the adoption gap is likely due to the greater prominence in the United States of industries and products (such as military products) requiring the use of AMTs.

A residual gap remains. This gap is proportionately similar for technologies in their early and later stages of diffusion respectively (see Table 30). This implies that the Canadian problem is not simply that of a late start.

The gap is greater for NC/CNC machines which have been available for over 30 years (Hicks, 1986, Table 20) than it is for computer-aided design which began to be used (outside the defence sector) about 20 years ago (Kaplinsky, 1983 p.41).

The relationship between the age of a technology and the Canada-U.S. adoption gap bears further exploration. A proxy measure of the age of a tech-

**Table 30**

**Difference in the Scale-Adjusted Percentage of Use by Age* of Technology**

| Question | Technology Class | Age | Scale Adjusted Percentage Difference in Use |
|---|---|---|---|
| 1. . . 3 | Design and Engineering | 0.48 | -22.9 |
| 4, 6. . . 8 | Fabrication and Assembly | 0.38 | -26.8 |
| 5 | NC/CNC Machines | 0.81 | -36.6 |
| 9. . . 10 | Automated Materials Handling | 0.30 | -32.4 |
| 11. . . 12 | Automated Testing | 0.49 | -19.1 |
| 13. . . 15 | Communications | 0.48 | -18.4 |
| 16 | Programmable Controllers | 0.73 | -23.4 |
| 17 | Computers for Factor Control | 0.56 | -35.1 |

* Age is defined as [Number of establishments using a technology/(Number of establishments using a technology + Number of establishments planning to use a technology)]. It varies between zero and one. It is calculated as a weighted average for the United States and Canada.

Source: Statistics Canada (1991) and Table 24

nology is $AGE_{ij}$ = (Percentage of establishments in the jth major group using the ith technology) / (Percentage of establishments in the jth major group using the ith technology + Percentage of establishments in the jth major group planning to use the ith technology).

This variable can be constructed using either or both the Canadian and U.S. AMT surveys. The value of AGE is reported by technology class in Table 30.

As a technology ages its cost should fall. Cost should therefore become a less important reason for not using a technology as it ages. The proportion of non-users citing cost as their reason for not using a technology can also be calculated from either or both the Canadian and U.S. AMT surveys. This proportion, calculated using both surveys, is reported by technology class in Table 31, where it is apparent that as a technology ages, cost becomes less important as a reason for not using it. This relationship is confirmed by the following regressions:

$$NCE_{ij} = .27 - \underset{(4.82)}{.15}\, AGE_{ij} \qquad r = .47 \qquad N = 85 \quad \text{(t-ratio in brackets)}$$

and

$$\ln\,[NCE / (1-NCE)]_{ij} = -.96 - \underset{(4.90)}{.95}\, AGE_{ij} \qquad r = .47 \qquad N = 85$$

where $NCE_{ij}$ = proportion of non-users in the jth major group citing non-cost effectiveness as a reason for not using the ith technology.

As a technology ages it should become more widely applicable and thus more evenly distributed across industries. Thus, the variance of the usage rate across industries should be lower for older technologies than for newer ones. This relationship is confirmed by the following regression:

$$COV3U_i = .19 + \underset{(8.84)}{.15/AGE_i} \quad N = 85 \quad r = .70$$

(t-ratio in brackets)

where $COV3U_i$ = the coefficient of variation (standard error divided by the mean) in the percentage of establishments in each of the three-digit industries covered by the U.S. survey using the ith technology (a Statistics Canada special tabulation).

**Table 31**

**Technology Age and Cost as a Reason for Non-Use**

| Question | Technology Class | NCE | AGE |
|---|---|---|---|
| 1. . . 3 | Design & Engineering | 0.18 | 0.48 |
| 4, 6. . . 8 | Fabrication and Assembly | 0.21 | 0.38 |
| 5 | NC/CNC Machines | 0.17 | 0.81 |
| 9. . . 10 | Automated Materials Handling | 0.28 | 0.30 |
| 11. . . 12 | Automated Testing | 0.23 | 0.49 |
| 13. . . 15 | Communications | 0.18 | 0.48 |
| 16 | Programmable Controllers | 0.15 | 0.73 |
| 17 | Computers for Factory Control | 0.18 | 0.56 |

In summary, the aging of a technology may be characterized by:

- a decline in the ratio of potential to actual users
- a decline in the importance of cost as a reason for non-use
- a decline in the interindustry variation in the incidence of use.

The measures of age can be used in a statistical test of the proposition that the adoption gap is greater (ie., less favourable to Canada) in the newest and the oldest technologies. This test can be performed holding two other possible influences on the adoption gap constraint:

- plant scale differences
- differences in the incidence of production to military specifications.

Differences in establishment scale are held constant by comparing the scale-adjusted Canadian adoption rate with the U.S. rate. The percentage difference between the scale-adjusted Canadian adoption rate and the U.S. rate is the dependent variable in the analysis.

A measure of the effect of production to military specifications ($MILNOM_i$) is the ratio of the proportion of U.S. establishments producing to military specifications and using the ith technology to the proportion of U.S. establishments *not* producing to military specifications and using the ith technology. This is an indicator of the importance of military production in explaining the use of a technology in the United States. It does not take into account the effect of any military production on the use of AMTs in Canada.

Estimation of the adoption gap model yields the following results:

$$PDUA_{ij} = -1.35 + \underset{(2.67)}{5.24}\, AGE_{ij} - \underset{(2.51)}{4.35}\, AGESQ_{ij}$$

$$- \underset{(2.37)}{.31}\, MILNOM_i - \underset{(1.45)}{1.26}\, NCE_{ij} + \underset{(1.56)}{.81}\, COV3U_i$$

$$R^2 = .10 \qquad N = 85$$

where $PDUA_{ij}$ = percentage difference between the scale-adjusted Canadian adoption rate and the U.S. adoption rate of the ith technology in the jth major group.

The results confirm that the adoption gap is wider for technologies used intensively by plants producing to military specifications. The adoption gap first narrows, then widens, as technology age (measured by the proportion of users to planned users) increases. The adoption gap widens with age for technologies aged .6 and older. NC/CNC machines, programmable controllers, and computers for factory control would be in this category.

The other explanatory variables are not significant. The negative coefficient of NCE implies that the more important is cost as a reason for non-use, the wider the gap. Offsetting this is the effect of COV3U which implies that the more uneven the inter-industry distribution of the technology, the narrower the gap.

These results imply that the Canadian "problem" may involve both slow adoption and no adoption. Canada tends to lag the U.S. more in the newest and oldest technology classes. The first finding supports concerns raised by earlier studies of the Economic Council (Economic Council of Canada, 1983) regarding slow diffusion to and within Canada. The second finding implies that the *ultimate penetration* of what Ray (1989) calls mature or saturated technologies is lower in Canada than in other industrialized countries. The issue here is not whether adoption is timely but why the technologies involved are ultimately less applicable in Canada. Thus, explaining Canada/U.S. differences in the percentage of establishments regarding a technology as applicable (see Tables 16 and 17) appears to be at least as important as explaining differences in the respective percentages of establishments using a technology. Indeed, *among establishments regarding a technology as applicable*, there may be no adoption gap.[23]

## Policy Implications

Some of the adoption gap discussed above may be eliminated by the Free Trade Agreement, but the attainment of U.S. scale levels by Canadian establishments may not be sufficient in and of itself to bring Canadian AMT use into line with that prevailing in the United States.[24] Perhaps a more integrated market in AMTs themselves, together with greater horizontal and vertical contacts between U.S.and Canadian firms, will have a salutary effect. This depends on the reasons why Canadian establishments are at present less inclined to use AMTs than their counterparts in the United States.

One implication of these results is that the minimum scale for AMTs to be economic is greater in Canada than in the United States. This implies, in turn, that fixed adoption costs are higher in Canada than in the United States. Variable adoption costs may or may not be higher in Canada. The AMT surveys provide no direct evidence on this issue.

The respective effects of differences in fixed and variable adoption cost can be illustrated using the following simple model. Let the cost of adoption be:

$$CA = c_0 + c_1 IQ$$

where CA = adoption cost per establishment in present value terms, I = proportion of establishment activity to which an AMT applies, I = 0. . . 1 and Q = establishment scale. Let the quasi-rents resulting from adoption be:

$$RA = r_1(I - r_2 I^2)\,Q \qquad r_1 \geq 2\,r_2$$

where RA = quasi-rent in present value terms.

The optimal proportion of activity to which a particular AMT is applied is:

$$I^* = (r_1 - c_1) / 2r_2$$

The threshold scale at which adoption becomes economic (ie., I > 0) is:

$$Q^* = 4c_0 r_2 / (r_1 - c_1)^2$$

The threshold scale $Q^*$ is an increasing function of fixed adoption cost $c_0$. This fixed cost is apparently higher in Canada than in the U.S.

If intra-establishment diffusion, $I^*$, were greater in the United States than in Canada, this would imply that variable adoption cost, $c_1$, is higher in Canada than in the United States. Since the AMT surveys reveal nothing about Canada/U.S. differences in $I^*$, no such inferences can be drawn.

Suppose, however, that AMTs are not infinitely divisible. Rather, there is a minimum throughput requirement Kmin = ($I^*Q$) min. In this case the minimum scale at which a particular AMT is economic is:

$$Q^* = (c_1 Kmin) / (r_1 - r_2)$$

In this case the observed Canada/U.S. difference in the threshold scale at which AMTs are adopted is the result of minimum scales on AMTs themselves, together with higher variable adoption costs in Canada.

Thus, observed scale-corrected Canada/U.S. differences in AMT use imply that fixed and/or variable adoption costs are higher in Canada than in the United States. These cost differences could come from many sources:

- higher hardware prices
- higher installation costs
- less favourable tax treatment of investment
- less subsidy support for technology acquisition
- higher planning and evaluation cost due to: weaker linkages with suppliers, less well-educated management, and/or less effective management structure
- higher integration costs due to a less well-trained workforce and/or shortages of skilled labour.

Each of these potential sources of cost difference should be investigated on its own. Some have been the subject of considerable study; some have not. While hardware prices may be higher in Canada, the Free Trade Agreement should reduce this disadvantage.

The tax treatment of investment is at least as generous in Canada as in the United States. U.S. assistance programs for advanced technology adoption have been channelled largely through the Department of Defence (see Ashburn, 1988, pp. 72-3). Canadian assistance may be more broadly distributed but, until recently, it may have been oriented more to either R&D or job "creation" rather than to technology adoption.

Supplier linkages, management education and innovation-oriented management structures have frequently been cited as associated with early adoption (see a recent Canadian example in Julien *et al.*, 1988). U.S. manufacturers may benefit from shorter distances as well as agglomeration economies in informing themselves about AMTs. Note, however, that the hypothesis that geographic isolation deters new technology adoption has received relatively little in the way of empirical support (see McFetridge, 1989 and Hicks, 1986, p. 100).

Well-trained workforces are more readily able to accommodate new technologies (Bartel and Lichtenberg, 1987). Shortages of skilled personnel have been cited as a barrier to technology adoption in Canada by Munro and Noori

(1986) and Betcherman and McMullen (1987). Whether these problems are more or less severe in the United States is another question.

Once the sources of the cost disadvantage faced by Canadian establishments are determined, the issue is then one of remedies. An adoption cost disadvantage can be offset with a subsidy. While this may encourage adoption, it may not address the underlying problem and could reduce rather than increase productivity. That is, where new technology adoption is retarded by real cost disadvantages, merely shifting the burden of these costs does not make the economy more productive.

A number of the potential sources of Canadian cost disadvantage do not lie in the cost of AMTs themselves but rather in the cost of planning and integrating. Reduction of these costs requires action in other policy areas and jurisdictions (such as education) and results may not be visible for many years.

Policy actions that have the potential to bring about a productivity-improving increase in AMT usage or in advanced technology usage in general take three forms. The first policy action is the internalization of any technology adoption externalities. An externality may occur if later adopters can free-ride on the experience of an early adopter of a new technology, or if AMT suppliers benefit from each other's marketing efforts. The results reported in the previous section may imply either that there may not be much in the way of transferable adoption experience to free-ride on, or that experience is transferred with appropriate compensation. If adoption experience were transferable from establishment to establishment and were partly appropriable but not salable at arm's-length, then multi-establishment enterprises should be more likely to adopt AMTs; but they do not. This does not leave much room for the existence of a demonstration effect externality, at least for AMTs.

The second type of policy which can bring about a productivity-improving increase in advanced technology usage is the elimination of restrictions or taxes on the supply of both these technologies and complementary inputs. The question here is whether there is a disproportionate tax or tariff burden on either AMTs or complementary inputs. The other question is whether there are immigration or provincial or union entry restrictions on the skilled personnel required to install and operate AMTs. Union work rules themselves may also increase the cost of integrating new technologies.

A third area in which public policy can be productive is to ensure that public sector institutions are adaptable and responsive. The obvious example is the educational system which has been criticized both for the generally poor quality of training it provides and for its slow response to emerging skill requirements.

These three types of remedies have the common characteristic of reducing the real cost of new technology adoption. In some cases this may involve the elimination of a market failure. In other, more likely, cases it involves the elimination of distortions imposed by other public policies, improving the effectiveness with which existing public sector institutions operate. Note that these changes are desirable for their own sake. The fact that the adoption of AMTs in Canada appears to lag the United States serves only to indicate that improvements of this nature are possible: it does not enhance their desirability.

Recent programs of technology adoption in Canada have tended to involve the subsidization of the evaluation and implementation function, particularly for smaller firms. This shifts rather than reduces the cost burden of new technology adoption and does not increase productivity (properly measured). A more appropriate focus is on the (social) resource cost of technology adoption. What is it that has made this cost appear to be lower in the United States than in Canada? The research required to answer this question involves the comparison of the respective costs of adopting a given new technology in matched (same scale, same three-diigit industry) Canadian and U.S. establishments. Once the specific sources of cost difference are ascertained, the discussion of appropriate remedial policies can proceed on an informed basis.

# Endnotes

1. The Industry, Science and Technology (1990a) survey concluded that many firms experience difficulties in finding experts in Canada "...who could identify the state-of-the-art equipment necessary for smooth and efficient implementation" (p.7).
2. One source of scale bias may be the cost of integrating new and existing technologies in the production process. See Cainarca, Colombo and Mariotti (1989, p. 65).
3. These costs can be much higher than the cost of hardware. For example see Miller (1985).
4. See Rose and Joskow (1988).
5. See Nicol and Hollier (1985).
6. Case studies explicitly rejecting the existence of regional effects on adoption include Hicks (1986) and Nijkamp and Mouwen (1987). Other studies find a regional pattern to adoption but are able to attribute it to factor prices (see Utterback and Kim, 1985).
7. There are two possible measures of three-digit AMT use. Each has its imperfections. The first is the percentage of establishments *including the ith establishment* using a technology. This is:

$$ITE_i = U / (U+N)$$

The alternative is to exclude the ith establishment from the calculation. Thus:

$$ITE'_i = (U-I) / (U+N)$$

where U = number of users in a given three-digit industry, N = number of non-users in a given three-digit industry, and I = 1 if the ith establishment is a user, zero if it is a non-user.

The variable ITE has only one value for each three-digit industry. This value is greater if the ith establishment is a user than if it is not. The variable $ITE'$ can take on either of two values for each three-digit industry. It takes on the lower value [(U-I) / (U+N)] if the ith establishment is a user. This implies a negative correlation between use and $ITE'$ *within* each three-digit industry which may or may not offset the positive correlation *across* three-digit industries. The negative within industry effect is more likely to dominate when there is relatively little variation in use among three-digit industries. This happens occasionally. Only results employing ITE are reported in this study.

8. The twelve major groups are: Clothing, Wood Products, Paper and Allied Industries, Printing and Publishing, Primary Metals, Fabricated Metal

Products, Machinery, Transportation Equipment, Electrical and Electronic Equipment, Non-Metallic Mineral Products, Petroleum Products, and Chemicals.

9. The term MCS on the right side of these tables is the Model Chi Square test statistic for the Likelihood Ratio Test of joint significance (see Amemiya, 1981, p.1498). The critical value of -2 at the 5 per cent level with 10 degrees of freedom is 18.3.
10. The scale elasticity of adoption is (dP / dS) (S / P) where P is the probability of adoption and S is scale. It is evaluated at the means of P and S respectively. Estimates are reported in Table 9.
11. At the time this statistical work was done, Statistics Canada had not constructed the Instruments and Related Products major group which is used in the Canada-U.S. comparisons in the final section. Much of the Canadian scientific instruments industry is in the Miscellaneous Manufacturing major group and is thus not included in this analysis.
12. Note, however, that when Dunne includes firm level R&D-intensity in his model his multiplant variable becomes insignificant (1991, Table 7). A possible interpretation of this result is that the accumulation of technological capability increases the incidence of both multiplant operation and the use of AMTs.
13. Julien *et al.* (1988) find that suppliers, trade fairs and research organizations are important sources of information. This implies that institutions which economize on transferable learning do exist. Whether they are as well developed as in other countries is another question.
14. The three-digit dummies and the growth in market share together reflect establishment real growth. The three-digit dummy reflects the effect of industry growth while the growth in market share reflects the growth of the establishment relative to the industry.
15. The percentage difference in the percentage of using establishments is calculated as $2(P_c - P_u) / (P_c+P_u)$ where $P_c$ is the percentage of users in Canada and $P_u$ is the percentage of users in the United States.
16. The greater incidence of non-applicability in Canada may also be a result of differences between Canada and the United States in the composition and/or method of production within a given major group. This might also help to explain why Canadian use of a number of mature technologies is well below that of the United States. This issue is examined further below in the last section of this paper.
17. U.S. Congress, Office of Technological Assesment and Forecast (1990), pp.152-6.
18. The Italian survey covers Metal Manufacturing and Products, Mechanical Engineering, Office and Data Processing Machinery, Electrical Engineering, Motor Vehicles and Parts, Other Transportation Equipment and Instrument Engineering.

19. The Australian results could also be compared to the Canadian results for all manufacturing establishments (Statistics Canada, 1989a). The conclusion that Canadian usage rates are generally higher continues to hold.
20. Statistics Canada does regard its shipment weights as a ccurate at the three-digit level and has published AMT usage rates based on them (percentage of three-digit industry shipments accounted for by establishments using one or more, five or more, or ten or more AMTs). See Statistics Canada (1991a) Unfortunately, the United States did not publish any shipment weighted results.
21. The difference in the industry composition of the two major groups can be summarized as follows:

| | **SIC Number(s)** | | **Establishment Weight in [Major Group]** | |
|---|---|---|---|---|
| Industry | Canada | U.S. | Canada | U.S. |
| Aircraft and Parts | 321 | 372, 376 | .234 | .238 |
| Motor Vehicles and Parts | 323, 324, 325 | 371 | .389 | .509 |
| Railway Rolling Stock | 326 | 374 | .064 | .031 |
| Boat and Shipbuilding | 327, 328 | 373 | .313 | .222 |
| **Total** | | | 1.000 | 1.000 |

Source: Statistics Canada, *Manufacturing Industries of Canada; National and Provincial Areas, 1982*, Table 4 and U.S. Department of Commerce, Bureau of the Census, *1982 Census of Manufacturers; General Summary Part 2 Industry Statistics by Employment Size of Establishment*, Table 2.

22. This is the percentage difference in the five major group weighted averages for each country.
23. The data in Table 16 imply a 35.6 per cent difference in the mean usage rate over all establishments and an 11 per cent difference in the (weighted) mean usage rate among establishments regarding the technologies as applicable.
    The simple average of the scale-adjusted percentage of users among those considering it relevant is 30.5 per cent for Canada. The simple average percentage of users among those considering it relevant is 28.7 per cent for the United States. Neither the difference nor the percentage difference in these two averages is statistically significant.
24. Trade liberalization is also expected to result in an increase in plant specialization or an increase in average batch size given scale. It is not clear what effect, if any, this would exert on the economics of AMT adoption. For a general discussion of this issue, see Gros-Pietro and Rolfo (1989).

# Appendix

### Factors Determining the Optimal Adoption Date

The profitability of an investment in I units of capital undertaken at time t is:

$$\Pi (I)_t = \int_t^{\infty} V(I)\, e^{-rt}\, dt - (S + C(I))\, e^{-gt} \qquad (1)$$

where:

| | |
|---|---|
| V (I) | = the annual flow of quasi-rents resulting from an investment in I units of capital |
| S | = search and shakedown cost |
| C (I) | = investment cost |
| r | = discount rate |
| g | = annual rate of decrease in search, shakedown and investment cost. |

The optimal scale of investment is such that:

$$\partial\Pi / \partial I = (V'(I) / r)\, e^{-rt} - C'(I)\, e^{-gt} = 0 \qquad (2)$$

Expression (2) states tht the present value of the incremental flow of quasi rents beginning on the installation date must be equal to the incremental (marginal) investment cost as of the installation date.

The optimal installation date is t* such that:

$$\partial\Pi / \partial t = -V(I)\, e^{-rt} + g\, (S + C(I))\, e^{-gt} = 0 \qquad (3)$$

Expression (3) states that at the optimal introduction date the loss in quasi rent from postponing adoption one period is just equal to the cost saving realized by postponing adoption by one period. Expression (3) can be solved explicitly for the optimal adoption date which is:

$$t^* = (\ln g + \ln (S + C(I)) - \ln V(I)) / (g - r) \qquad (4)$$

The optimal adoption date may depend on the scale of investment. Thus:

$$\partial t^* / \partial I = [\, (C'(I) / (S + C(I)) - V'(I) / V(I)\, ] / (g - r) \qquad (5)$$

Expression (5) implies that the optimal adoption date does not depend on the scale of investment if there are constant returns to scale in the new capital ($V' / V = C' / C$) and search and shakedown costs (S) are zero. If there are increasing returns to scale in the new capital ( $V' / V > C' / C$ ) or if fixed adoption costs (S) are positive, the optimal adoption date is earlier the larger the scale of investment. This implies that, other things being equal, larger scale plants will be earlier adopters than smaller plants.

Equation (5) also implies that the greater the rate at which the cost of a new technology is declining, the smaller the effect of scale differences on the optimal adoption date ($\partial^2 t^* / \partial I \partial g \rangle 0$).

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