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**INTANGIBLE CAPABILITIES AS  
DETERMINANTS OF ADVANCED  
MANUFACTURING TECHNOLOGY  
ADOPTION IN SMEs: TOWARD AN  
EVOLUTIONARY MODEL**

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# Intangible Capabilities as Determinants of Advanced Manufacturing Technology Adoption in SMEs: Toward an Evolutive Model

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Jean Harvey<sup>‡</sup>

## Abstract / Résumé

*This paper investigates the relationship between intangible capabilities and further AMT adoption in 116 small manufacturing firms. Results indicate that skills of blue-collar workers, influences of customers and vendors, and motivations focussed on process improvement and customers are the strongest determinants of subsequent levels of adoption. Further, it is shown that strategic motivations moderate the relationships between technical skills and influences, and further AMT adoption. Preliminary support for an evolutionary model is also leading to a revised conceptual framework.*

Dans ce papier, la relation entre les compétences intangibles et l'adoption subséquente de technologies avancées de production est étudiée dans un échantillon de 116 petites entreprises manufacturières. Les résultats indiquent que les compétences des cols bleus et l'influence des clients et des fournisseurs de technologies sont dominantes. De plus, il semble exister certains indicateurs préliminaires suggérant l'existence d'un modèle évolutif.

Key words : learning model, technology adoption, small manufacturing firms

## 1. INTRODUCTION

The new rules of competition imposed by the increased globalization of markets and rapid technological changes are among the realities with which organizations must comply. This obviously creates a strain on the capacity of organizations to adapt to both external and internal pressures and, as a result, to manage change. When technological change is sought, skill remain a key element that needs to be dealt with [1]; indeed, they constitute the factor which most directly affects the attainment of an organization's goals. Rogers [2] long ago documented the fact that the innovation adoption process is a social one. Since then, much work has been done to investigate the individual roles [3, 4], the critical functions [5], and the networks [6, 7], which must be present to sustain the innovative capacity of organizations, all of which points to the importance of mobilizing human capital to ensure successful change in organizations.

This study focuses on one specific type of innovation, namely process innovation in the form

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of advanced computer-based manufacturing technology (AMT) adoption. Two basic premises will guide this study. The first is that innovation adoption must be considered in the context of a firm's acquired capabilities and know-how and as such is evolutionary in nature. This implies that the adoption of further AMTs is constrained by past experience and acquired skills and knowledge. The second premise is that many of these capabilities are intangible. Both of these premises are explored in the specific context of small manufacturing firms.

## **2. THEORETICAL CONSIDERATIONS**

This paper seeks to combine two streams of research: the adoption of innovations as an evolutionary process and the crucial importance of intangible capabilities. By integrating these two perspectives, a proposed framework is derived.

### **2.1 Determinants of the adoption of innovations: towards an evolutionary model**

In the innovation adoption literature, previous research work has largely concentrated on the various factors which may ultimately affect adoption. From this rich theoretical corpus, emerging from various fields ranging from economics to organizational theory, several lines of research can be identified. One influential group has stressed the importance of environmental factors: societal values [8,9], government policies, and trade, fiscal or industrial policies [10,11,12] may encourage the adoption of innovations. Furthermore, firms tend to react or adjust to competitive uncertainties generated by market and technological

changes. As such, both the competitive and technological environments have been shown to strongly influence a firm's strategy, and ultimately, innovation adoption decisions [13,14,15].

Although the importance of these environmental factors on innovation adoption must not be forgotten, they are partially taken into account during the innovation decision process. In fact, the capabilities of a firm to gather, interpret and use external information and to adapt to external environments can be viewed as an integral part of organizational learning. In exploring the practices of the learning organization, Garvin [16] has identified experimentation with new approaches, learning not only from the experience and best practices of others but from a company's own experience as three key practices. In the same line of inquiry, Pavitt [17] has also demonstrated that firms follow technological "trajectories" which cannot be dissociated from what they have already learned. There is growing evidence that technology adoption may be subject to a firm's prior experience with technology [18,19], and that organizational knowledge and skills may ultimately be a major determinant of the adoption rationale [20]. Thus, strategy formulation can be viewed essentially as a "social learning process" through which the technology strategy emerges from acquired technical capabilities, which themselves are shaped by past technological experience. It is argued here that, in order to improve its innovative capacity, an organization must rely mainly on its internal forces.

## **2.2 Intangible capabilities as determinants of AMT adoption**

A great deal has been written on the determinants of AMT adoption. Yet, in an increasingly competitive context, AMTs remain a crucial concern for most manufacturing firms due to the financial and strategic implications of their adoption. The focus of the present paper is on intangible capabilities as determinants of AMT adoption, and these capabilities will be shown to constitute important factors.

### *Technical skills*

Employee skills at all levels (Steedman and Wagner, 1989), and especially technical skills, have been shown to facilitate technological innovation and a lack thereof inhibits the installation of technically complex equipment due to a poor understanding of the technical potential of the equipment and the suspicion that "the equipment manufacturers were trying to pull a fast one" [21:56]. This was found to be true not only for foremen and supervisors but also at the level of blue-collar workers [21] and machinists [22] operating NC machines. In their comparative analysis of British and German workers, Daly et al. [21] found that the NC machines installed by British manufacturers were not used to their full capacity because of the workers' lack of technical competence. In dealing with the acquisition and use of the more advanced manufacturing technologies such as CAM, Majhrach [23] and Gerwin & Kolodny [24] also stress the importance of having a broad range of capabilities among all

levels of workers whether they be operators, maintenance workers, engineering professionals or managers.

### *Influences*

Although individual learning is crucial, it is a necessary, but not a sufficient condition for organizational learning to take place. In their recent comparison of organizational practices at NUMMI (New United Motors Manufacturing Inc. - A GM-Toyota joint venture) and Uddevala (Sweden, Volvo), Adler and Cole [25] showed that mechanisms must exist to capture individual and team learning and propagate it throughout the company, thereby transforming it into organizational learning. While the mechanisms through which this propagation takes place and the nature of organizational arrangements which are most conducive to this learning are vigorously debated [26], they necessarily involve a combination of organizational capabilities, individual skills and influences.

Research conducted by Dean [4] also suggests that the justification process for AMT adoption is largely dominated by the influence of its proponents. Decision-making participants usually considered as influential proponents in past research include internal actors, in particular the CEO [27] and the production and marketing managers [4]. AMT adoption decisions are also to a large extent moulded by the external proponents. A long stream of empirical research emphasizes the importance of the supplier-adopter relationship [28,29]. The supply side [15], usually represented by vendors of equipment and consultants,

greatly affects the AMT adoption decision [24]. Finally, firms adopt AMTs in order to meet customers' requirements and/or expectations [30].

All of these internal and external influences provide, directly or indirectly, an indication of how the firm perceives its external environment, deals and learns from it, however distorted this may turn out to be [31].

#### *Strategic motivations*

The justification of advanced manufacturing technologies has generated numerous articles in a wide variety of literature, as demonstrated by the comprehensive bibliography collected by Son [32]. When a firm gains experience with AMT, it moves away from the short-term quantifiable benefits and investigates different options which should be embedded within the overall strategic process [33,34]. Strategic considerations therefore gain more weight with increased technological experience and are shown to be important factors in the decision to adopt flexible manufacturing systems [35]. Key factors identified as important priorities for a manufacturing strategy include cost, productivity, quality and flexibility [36]. These same criteria are also found to be pertinent in the case of decisions regarding the adoption of manufacturing technology [37] and represent crucial strategic motivations.

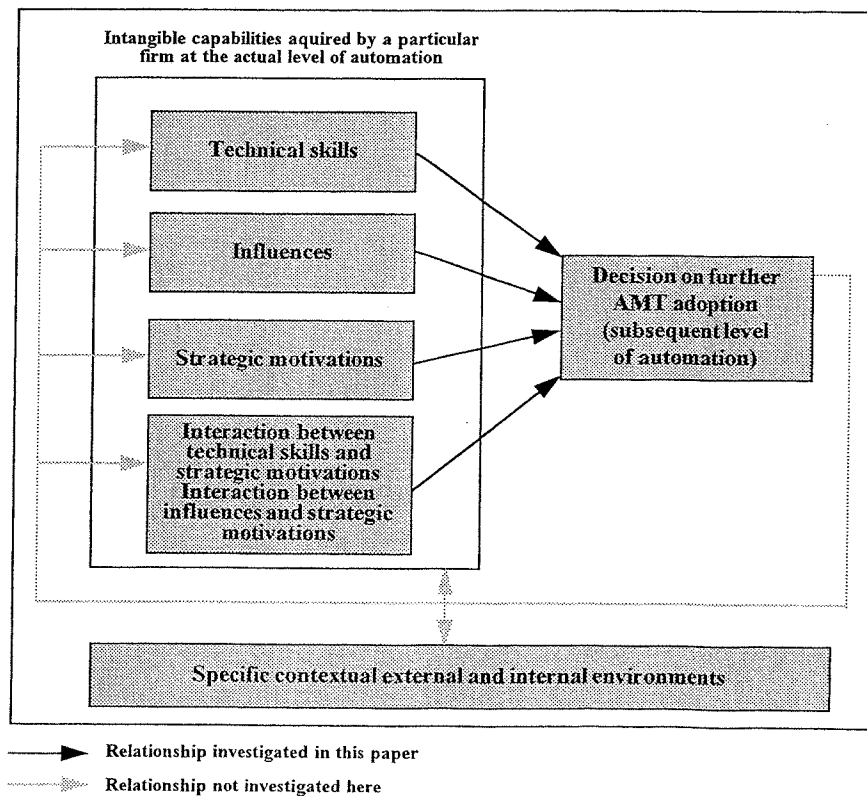


### 2.3 The evolutionary nature of intangible capabilities and their impact on AMT adoption:

#### A proposed framework

The above discussion stresses the importance of intangible capabilities in the form of employee skills, influences and strategic motivations which are the dimensions retained in this study (figure 1). From an evolutionary perspective [38, 8], these acquired necessary distinctive capabilities should promote a higher level of technology adoption.

**Figure 1**  
**Intangible capabilities as determinants of further AMT adoption**



Furthermore, strategic motivations may modify the strength and form of the relationships between technical capabilities and influences and the adoption of AMTs. For example, when attempting to enhance marketing performance in terms of improvement of corporate image or of quality customer services in the form of more dependable, faster deliveries, it is expected that the marketing group would have the strongest involvement and that the technical capabilities of professionals and managers would constitute a more important determinant than the technical capabilities of blue-collar workers. However, if the emphasis on strategic motivations is placed on the reduction of production costs, the production group should have a strong influence and the technical capabilities of blue-collar workers might prevail. Hence, strategic motivations act as moderating variables [39]. This is acknowledged in figure 1 by the interaction terms (fourth box on the left-hand side of figure 1).

#### **2.4 The specific context of SMEs**

The relationships presented in figure 1 are investigated in the specific context of SMEs. The economic importance of these smaller firms, their propensity to be innovative [40,41], and the fact that they are rather accessible sites for the observation of complex phenomena justify this choice. In addition, the relative importance of intangible capabilities as determinants of AMT adoption may be different in SMEs than in their larger counterparts.

Small firms are under increasing pressure to rely on AMT adoption to maintain their competitive position or simply to survive and, in the case of small subcontracting firms, the modernization of their facilities is often dictated by major customers. At the same time, barriers to adopting sophisticated technology in SMEs are more numerous than in larger firms due to the usually large capital investment and skilled manpower involved in the implementation and operation of such technologies. Further, potential benefits derived from the adoption of AMTs are sometimes difficult to realize fully [42] and, in the absence of internal expertise, serious doubts can be raised about the realization of such benefits in SMEs. Therefore, given that some CEOs of SMEs view AMT adoption as a "necessary evil" and most are aware of the considerable risks involved, it is expected that the relative importance of intangible capabilities as determinants of AMT adoption would differ in SMEs. In fact, Meredith's studies have demonstrated that SMEs tend to seek different competitive advantages from AMT adoption than larger firms and therefore the emphasis would be placed on different strategic considerations. Rothwell and Zegveld [43] have also stressed the crucial importance of employee participation in SMEs and its impact on the outcome of the decision-making process. Although participative in nature, the decision-making process is also undoubtedly subject to the CEO's strong influence [27], especially in the smaller SMEs. It must also be recognized that small firms may be more outward-oriented than larger ones [44] and therefore more sensitive to the external influence of customers. Finally, SMEs rely heavily on technology suppliers and consultants since, in many situations, they lack the internal expertise to correctly address the problem or

opportunity at hand.

### **3. METHODOLOGICAL ISSUES**

#### **3.1 Operationalization of research variables**

Measures for all research variables were extensively pre-tested in an on-site study carried out in 44 small manufacturing firms using semi-structured interviews [45].

##### *Independent variables*

The first set of independent variables, corresponding to the acquired technical capabilities of the different categories of employees, was measured as the actual percentage of employees within each category who were using computer-based technologies on a daily basis in their work activities. The second and third sets of variables were measured on 7-point Likert scales. Questions relating to influence were formulated as follows: "What is the degree of influence of the following groups or individuals [CEO] on further AMT adoption decisions?". The criteria used here (Appendix 1) correspond to the operational measures offered by Miller and Roth [46] to assess manufacturing success in terms of the quality of products, flexibility of the manufacturing process and delivery whereas other measures were derived mainly from the work of Pimrose and Leonard [47]. The original list of criteria pre-tested in the previous on-site study was fairly long. As a result, some

criteria were deleted either because they were poorly understood by CEOs or because they did not really apply to the specific context of SMEs. As an example, the concept of market scope, defined by Roth and Miller [48] in terms of broad distribution, broad product line, effective advertising and after-sales service, did not prove to be as pertinent in SMEs as it would be in larger firms (with the exception of after-sales service). Construct reliability for all perceptual variables proved to be quite satisfactory with Cronbach alphas coefficients ranging from 0.68 to 0.92.

#### *Dependent variable*

The subsequent level of technological penetration in a firm was measured taking into account the advanced manufacturing technologies considered for adoption by the firm in the upcoming 24-month period. In order to provide an indication of the degree of radicalness, known to be an essential secondary attribute of innovations [49,50], a panel of 20 experts familiar with AMTs and with small manufacturing firms were asked to evaluate on scales ranging from 1 to 7 the incremental versus radical nature of each of the computer-based production technologies considered are presented in appendix 2. These experts (four from the academic sector, six from the public or parapublic sector and ten from the private sector) were contacted in person to request their participation and to specify the context and survey objectives. In particular, the radical nature of each AMT considered in this study was defined as "radical and revolutionary changes, clear departure from existing practices" and the incremental nature was defined as "minor changes and minor improvements". Inter-rater

reliability proved to be very satisfactory ( $r = .90$ ) and the Kendall test of concordance ( $p = 0.0038$ ) indicates that the twenty experts were in almost complete agreement.

A "score of automaticity", was then derived for each firm using the following weighted sum:  $\sum AMT_i r_i$  where  $AMT_i$  = advanced manufacturing technology<sub>i</sub> being considered for adoption in a 24-month period and  $r_i$  = mean rank for the degree of radicalness as assessed by the panel of experts. This score is the dependent variable.

### **3.2 Sample and respondents**

The sample retained here was drawn, using systematic sampling procedures, from a government directory of all manufacturing firms operating in Quebec. Response rate was 12.1% which is not unusual for large mail surveys. No follow up was done. The responding firms did not display any particular sectorial bias when compared to the Quebec and Canadian populations of manufacturing firms (goodness of fit tests: respectively  $\chi^2 = 8.158$ ,  $p = 0.417$ ;  $\chi^2 = 5.968$ ,  $p = 0.651$ ) and to the U.S. population of manufacturing firms ( $\chi^2 = 8.348$ ,  $p = 0.400$ ). These tests were performed using published data on the number of manufacturing firms classified by two-digit Standard Industrial Codes [51,52]. Responding firms came from every major industrial sector including plastics, chemicals, metal, electronics, food and furniture.

In order to obtain a more homogeneous sample in terms of firm size, only firms with more

than 50 and fewer than 200 employees are analyzed here. The lower limit was arbitrarily set to allow for representation of the different employee categories, while the upper limit corresponds to one of the accepted definitions of SMEs [53]. Firms reporting to the head office of a parent company were discarded since technological choices, and particularly AMT adoption, might have been dictated by the head office. All subsequent statistical analysis was therefore performed on 116 independent SMEs.

By imposing these restrictions on the sample, certain characteristics of the external environment such as trade, fiscal or industrial policies and of the internal environment such as formalization or centralization are partially controlled for by focusing on independent firms of similar size actively operating in the same geographic region.

The top manager or CEO of each of the firms chosen received a pre-tested questionnaire which he/she had to fill in. His/her overall knowledge of the characteristics of the organization and of its strategy and performance makes him/her an ideal source of information [54], especially in SMEs [55].

### **3.3 Statistical analyses**

Factor analysis with varimax rotation was first conducted on each of the three sets of variables in order to uncover the relationships within each set and ultimately reduce the number of variables to a limited number of orthogonal factors (tables 1, 2 and 3). These

factors were considered as independent variables in a hierarchical multiple regression analysis in order to evaluate the contribution of each set of variables to further AMT adoption (table 4). Finally, moderated regression analysis (table 5) allows us to test the interaction effects between strategic motivations, and, technical capabilities and influences, on AMT adoption [56].

## **4. RESULTS AND DISCUSSION**

### **4.1 Factorial analyses**

Results of the principal component analysis performed on each of the three sets of variables are shown in tables 1, 2 and 3 respectively. All loadings greater than .60 were considered as statistically significant [57].

The underlying dimensions revealed in table 1 can clearly be labelled as "technical capabilities of white-collar workers" (FC1) and "technical capabilities of blue-collar workers" (FC2). Both factors together accounted for 67% of the variance among variables pertaining to technical skills.



**Table 1**  
**Results of varimax rotated principal components**  
**analysis for technical capabilities**

Technical capabilities of:	Mean percentage (n=116) %	Factor 1 (FC1)	Factor 2 (FC2)
Clerical employees	70.97	<u>0.78</u>	-0.03
Secretaries	72.39	0.53	0.41
Managers	56.63	<u>0.77</u>	0.30
Professionals	57.78	<u>0.78</u>	0.16
Blue-collar workers	14.03	0.10	<u>0.95</u>
Percentage of total variance explained by each factor		48.8%	17.2%
Cumulative percentage of total variance explained		48.8%	66.0%

As can be noted from the means presented in this table, the greatest users of computer-based technologies are clerical and secretarial workers, who are usually the first groups involved in the use of information technologies. In SMEs, these two groups of employees are heavily involved with computer-based applications such as basic financial accounting or word processing and, in most firms, cost accounting, inventory control or billing, which are applications closely related to production operations. The technical capabilities of these employees contribute to a more "technical organizational climate" and may indirectly influence technology strategy. Further, in many cases, a spiral effect seems to be associated with the new capabilities brought about by the new manufacturing technologies: for example, firms can now provide an increasing number of customized products which ultimately require more sophisticated systems to ensure adequate control and follow-up of all manufacturing activities. The low percentage of blue-collar workers exposed to computer-based technologies reflects the current low penetration of AMTs in smaller manufacturing firms.

The results in table 2 do not present any interpretive difficulties. The first factor is clearly dominated by the influence of consultants and suppliers of technologies (FI1). These external influences are indeed known to be crucial for smaller firms. The second factor (FI2) relates to the influence of functional groups, whereas the third (FI3) and fourth (FI4) factors point to the influence of the CEO and the customers respectively. The four factors, which together explain 87.3% of the variance, were labelled respectively "influence of vendors", "influence of functional groups", "influence of CEO" and "influence of customers". From the means shown in table 2, it should be noted that the strongest single influence is that of the CEO. Although this is largely supported by the literature, some caution should be exercised since it is the CEO who is actually doing the reporting. The internal functional groups with the exception of the marketing group appear to be more influential in general than external groups.

**Table 2**  
**Results of varimax rotated principal components**  
**analysis<sup>1</sup> for influences**

Influences:	Mean (n=116)	Factor 1 (FI1)	Factor 2 (FI2)	Factor 3 (FI3)	Factor 4 (FI4)
<b>Internal influences on AMT adoption decision</b>					
Influence of chief executive officer	4.32	-0.03	-0.01	<u>0.98</u>	2.07
Influence of engineering and production group	3.47	0.25	<u>0.89</u>	0.16	0.00
Influence of marketing group	2.24	-0.04	<u>0.91</u>	-0.22	0.34
<b>External influences on AMT adoption decision</b>					
Influence of consultants	2.64	<u>0.70</u>	0.06	0.04	0.05
Influence of suppliers of technologies	2.43	<u>0.84</u>	0.15	-0.04	0.25
Influence of customers	2.46	0.24	0.19	0.09	<u>0.93</u>
Percentage of total variance explained by each factor		39.0%	19.5%	17.6%	11.2%
Cumulative percentage of total variance explained		39.0%	58.5%	76.1%	87.3%

<sup>1</sup> All variables are measured on a 5-point Likert scale (1 = very low influence, 5 = very high influence).

Table 3 outlines the strategic motivations for AMT adoption. For all 116 firms, increase in overall productivity received the highest ranking mean followed by increase in the quality of customer services. It appears that cost reductions (labor costs and cost of finished products), although quite important, are not the primary concern. As Meredith [44] has indicated, smaller manufacturing firms rarely compete on cost leadership alone but rather tend to exploit other competitive advantages such as greater customization and higher quality of the products and services offered.

**Table 3**  
**Results of varimax rotated principal**  
**components analysis<sup>1</sup> for strategic motivations**

Strategic motivations:	Mean (n=116)	Factor 1 (FS1)	Factor 2 (FS2)	Factor 3 (FS3)
Reduction in cost of finished product(s)	3.63	0.47	<u>0.65</u>	0.19
Reduction in labor costs	3.86	0.14	<u>0.74</u>	0.04
Increase in overall productivity	4.36	<u>0.73</u>	0.41	0.00
Increase in the quality of product(s)	3.85	<u>0.64</u>	0.34	0.27
Increase in the quality of customer services	4.15	0.56	0.15	<u>0.67</u>
Superior image of the firm	3.58	0.07	0.06	<u>0.96</u>
Increase in the flexibility of the manufacturing process	3.71	<u>0.91</u>	0.08	0.13
Percentage of total variance explained by each factor		49.8%	15.3%	10.9%
Cumulative percentage of total variance explained		49.8%	65.1%	76.0%

<sup>1</sup> All variables are measured on a 5-point Likert scale (1 = very low influence, 5 = very high influence).

Three factors (FS1, FS2 and FS3) are derived from the factorial analysis which accounted for 76.0% of the variance explained. They can be interpreted as follows:

FS1: Process improvement motivation, i.e., improving a combination of the major process attributes: productivity, quality and flexibility. This is a modern strategy that factors in the

need to meet world-class competitors.

FS2: Cost reduction motivation. This is generally a reactive or defensive strategy. In the former, it sometimes takes the form of blind - and often counterproductive - cost cutting. This is often a strategic motivation by default, reflecting a lack of understanding of the strategic advantages to be gained in today's environment through quality, flexibility and productivity enhancement. New technologies are often adopted with a view to replacing workers, rather than empowering them. Relying strictly on cost reduction motivation is a defensive strategic move that companies are compelled to make - often in the context of a crash program - just to stay in the game and curtail short term losses.

FS3: Customer focussed motivation. It reflects a company intent on helping customer get the results they want from its products and in forging long term relationships with them. Companies that adopt such an approach have often achieved a high level of mastery of their production process - which in some industry is merely a "qualifier" - and are competing on a higher-level "order-winning criteria" [30]. Customer focus is the central tenet of total quality management.

#### **4.2 Regression analysis**

Results of a multiple hierarchical regression analysis conducted on four blocks of variables are presented in table 4. Blocks of variables are entered progressively starting with the

control variable (block 1) and followed by blocks 2, 3 and 4 which represent, respectively, the technical capabilities, influences and strategic motivations. The dependent variable is the subsequent level of AMT penetration.

First, the control variable, firm size, has a positive relationship to further AMT adoption, but only accounts for less than 3% of variance [ $R^2 = 2.47\%$ ,  $p < 0.05$ ], which is not overly surprising given that the only firms considered for this research were SMEs with more than 50 and fewer than 200 employees. Obviously, this restriction minimizes the effect of firm size, which had been identified by a number of authors (see for example, Noori [58]) as an important predictor of AMT adoption.

When entering the second block, we witness a sharp increase in the explained variance ( $\Delta R^2 = 30.32\%$ ,  $p < 0.0001$ ). The technical capabilities of blue-collar workers are related significantly and positively to the subsequent level of AMT penetration. This could correspond to Adler and Clark's "experiential learning-by-doing, or first order learning" [53:270]. In fact, it could reasonably be assumed that the smaller manufacturing firm relies mostly on this form of learning. Indeed, skilled blue-collar workers already experienced with the functioning and operation of AMTs are a rare commodity; acquiring and retaining such skilled workers constitutes a formidable challenge for smaller manufacturing firms. In most cases, SMEs must invest heavily in on-the-job learning whereby blue-collar workers acquire skills and capabilities with technology through ongoing exposure to and use of the more sophisticated machinery. Yet this does not always translate into longer-term benefits for

smaller firms since a significant percentage of these skilled blue-collar workers prefer to leave for the better paying jobs and improved working conditions offered by larger firms.

**Table 4**  
**Hierarchical multiple regression analysis<sup>1</sup>**  
**with the subsequent level of AMT**  
**adoption as dependent variable**

Independent variables:	Model 1	Model 2	Model 3	Model 4
	$\beta$	$\beta$	$\beta$	$\beta$
<b>Block 1: Control variable</b> Ln of annual sales	0.16***	0.13*	0.14*	0.12*
<b>Block 2: Technical capabilities</b> FC1: White-collar workers FC2: Blue-collar workers		0.09* 0.53****	0.05 0.49****	0.06 0.45***
<b>Block 3: Influences</b> FI1: Vendors FI2: Functional groups FI3: CEO FI4: Customers			0.15* 0.03 0.00 0.19**	0.12* 0.05 0.01 0.15*
<b>Block 4: Strategic motivations</b> FS1: Process improvement FS2: Cost reduction FS3: Customer focussed				0.18** 0.00 0.14*
R <sup>2</sup>	2.47% *	32.79%****	37.62****	40.64%***
$\Delta R^2$		30.32%***	4.83%	3.02%

- \* p < 0.10
- \*\* p < 0.05
- \*\*\* p < 0.01
- \*\*\*\* p < 0.001

<sup>1</sup> Basic assumptions for conducting regression analysis are met because of the large sample size; the assumption of multivariate normality is not rejected; the independent variables are not highly correlated; finally, analysis of residues indicates no violation of basic assumptions.

<sup>2</sup> Standardized betas and adjusted R<sup>2</sup> are shown here.

$\Delta R^2$  = Change in R<sup>2</sup> after each step of the hierarchical regression. F test is performed using the following formula:

$$F = \frac{\Delta R^2 / M}{(1 - R^2) / (n - k - 1)}$$

where M is the number of independent variables added from model 1 to model 2, n is the number of respondents and k is the number of variables in model 2.

The effect of white-collar workers is significant though far less important. It is possible that white-collar workers are experienced with computer-based information technologies but have little knowledge in the use of manufacturing technologies. It may well be the case that the integration of information and production technologies is not yet a reality in smaller firms.

Introducing block 3 marginally increases the total explained variance to 37.62%. External influences are undoubtedly important determinants of AMT adoption. In particular, customers ( $\beta = 19$ ,  $p < 0.05$ ) are significantly associated with further AMT adoption. Consultants and suppliers of technology also seem to carry substantial weight when it comes to acquisitions of new technology: these external parties provide the expertise and competencies which smaller firms often lack. Furthermore, market pressures to become more productive may make these outside experts more attractive to smaller firms that are hoping to improve their operations. Although the CEO's influence is predominant, this influence does not appear to vary with the level of technological penetration of the firm. The functional groups' influence is also not associated with the level of further AMT adoption. This partially contradicts the results of previous studies indicating that the influence of the engineering production groups was a major discriminant factor between adopters and non-adopters of AMTs [19]. It would appear that the first inroads on the part of factory automation require heavy involvement on the part of certain internal groups such as engineering and production, which may act as major proponents. As the firm moves in the direction of acquiring additional AMTs, other factors come into account, namely, the technical capabilities of blue-collar workers and the presence of external networks.

When block 4 is added to the regression equation, the total explained variance increases to 40.64%. Cost-oriented strategic motivations are not more closely related to further AMT adoption but, both process improvement and customer focussed motivations have significant and positive relationships with the subsequent level of technological penetration. This confirms previous studies that have shown that, while cost considerations prevailed during the first stages of automation, in the later stages firms tended to broaden their expectations to include long-term, less quantifiable benefits [59].

#### **4.3 Moderated regression analysis**

In order to investigate the role of each dimension of strategic motivations (FS1, FS2, FS3) as a moderating variable, interaction terms were added to the main effects (table 5). The addition of these interaction terms proves to be most significant for FS1, leading to a sharp increase of 9.71% in the explained variance, and least significant for FS2.

When examining the contribution of each interaction terms to the explained variance, only 6 interaction terms out of 18 are found to be significant (FC1 x FS1, FC2 x FS1, FI3 x FS1, FC2 x FS3, FI3 x FS3 and FI4 x FS3) and all are positive. These six interactions terms can be interpreted as follows:

FI4 x FS3 (Customers' influence and a customer focussed strategic motivation).

It may sound like a truism, but customer's influence on further technology adoption is stronger for companies that are more focussed on customers. A company's intent on



pleasing, impressing, even delighting its customers is more likely to listen to their suggestions for improving its technological posture.

**Table 5**  
**Summary of results of moderated regression analysis**

	Moderating variables		
	FS1	FS2	FS3
Main effects (1) adjusted R <sup>2</sup>	39.01 ****	37.63 ***	38.49 ***
Adding interaction terms (1) cumulative adjusted R <sup>2</sup>	48.72 ***	40.33 **	43.26 ***
ΔR <sup>2</sup> (2)	9.71% *	2.70%	4.77%

- \* p < 0.10
- \*\* p < 0.05
- \*\*\* p < 0.01
- \*\*\*\* p < 0.001

(1) For FS1 as a moderating variable, the main effects are size, FC1, FC2, FI1, FI2, FI3, FI4 and FS1 whereas the interaction effects are FC1 x FS1, FC2 x FS1, FI1 x FS1, FI2 x FS1, FI3 x FS1, FI4 x FS1.

Similar moderated regression analysis is performed for FS2 and for FS3.

(2) Standardized betas and adjusted R<sup>2</sup> are shown here.

ΔR<sup>2</sup> = Change in R<sup>2</sup> after each step of the hierarchical regression. F test is performed using the following formula:

$$F = \frac{\Delta R^2 / M}{(1 - R^2) / (n - k - 1)}$$

where M is the number of independent variables added from model 1 to model 2, n is the number of respondents and k is the number of variables in model 2.

FC2 x FS1 (Blue-collars' technical capabilities and process improvement motivation)

FC2 x FS3 (Blue-collars' technical capabilities and customer focussed motivation)

The technical skills of blue-collar workers will bear more heavily on further AMT adoption when the strategic intents are to use technology to achieve higher process performance levels and increased customization. On the other hand, they may impede higher levels of automation if the strategic motivation is placed on cost reductions and perceived by workers

as a means to replace them.

FC1 x FS1 (White-collars' technical capabilities and process improvement motivation)

Improving quality, flexibility and productivity through technology requires a conjunction of efforts on the part of blue-collar and white-collar workers. Indeed, a lot of the improvement is achieved through integration between what takes place in the office and what takes places on the shop floor. Thus, it is not surprising to find that for companies that make the pursuit of process improvement their more central strategic motivation, the technical abilities of white-collar workers play a more significant role in technology adoption.

FI3 x FS1 (Influence of CEO and process improvement motivation)

FI3 x FS3 (Influence of CEO and customer focus motivation)

Process improvement motivation and customer focus motivation are aggressive and modern strategic orientation, fit to meet world-class competition. They are generally a reflection of a pro-active CEO and are unlikely to be adopted without strong strategic directions from the top. Thus, it is unsurprising to see that the CEO of these companies is much more of a factor in technology adoption than in companies where cost-cutting "at any cost" is the order of the day.

In summary, table 5 presents some evidence of moderation for FS1 and FS3 but not for FS2.

#### 4.4 Research limitations

A number of limitations should be taken into account when interpreting the study results. This research was conducted in a very specific context, that of smaller manufacturing firms. However, even though firm size was controlled for by limiting the range to more than 50 and fewer than 200 employees, it was shown that size still played a certain role (table 4). This suggests that close attention needs to be paid to this variable, which has been shown to be a proxy for other structural variables, such as complexity and technocratization [60]. The fact that the CEO acted as respondent may have introduced a bias in some cases, but most authors agree that this person is the most qualified respondent, especially in smaller firms. Another limitation probably relates to the operational definition of the dependent variable. The operational measure of the subsequent level of AMT penetration, in this case the cumulative count of AMTs being considered for adoption, does not assess the degree of future integration of these technologies, although the degree of radicalness is captured. Assessing the degree of future integration would have required on-site studies with a smaller number of participating firms. Finally, the cross-sectional nature of this research is a serious limitation as only intentions related to further AMT adoption are considered here. Will these intentions become a reality in a near future? The short-term horizon partially minimizes such potential distortion. In previous on-site studies, most of the SMEs (83.5%) actually did engage in the adoption process. However, a long-term horizon (5 years) proved to be too speculative. Finally, because of the cross-sectional nature of the data collected, the model proposed in figure 1 was not fully tested: the feedback loop between the

subsequent level of AMT and next level of acquired intangible capabilities was not investigated and, further, regression analysis does not permit one to establish causal relationships, even suggestive ones. Detailed longitudinal studies are therefore required to better understand the true nature of the observed relationships.

## **5. RETHINKING THE CONCEPTUAL FRAMEWORK**

While our original model generally holds true, reality appears to be more complex. The feedback loops shown in figure 1, which were not incorporated in our survey, appear to create a dynamic which is hard to apprehend through a cross-sectional study, and probably account for some of the difficulty in interpreting our results.

For instance, the relationship between technology and workers in the factory is complex and somewhat controversial. It has been argued that technology deskills work and destroys jobs. On the other hand, as technology increasingly assumes the burden of repetitive operations and as the rate of new product introduction continues to rise, highly skilled workers are required on the shop floor to develop and optimize processes. Also, multi-skilling often accompanies the introduction of flexible automation, as competition drives companies to target increasingly small market segments, thus putting a premium on the flexibility that generates economies of scope.

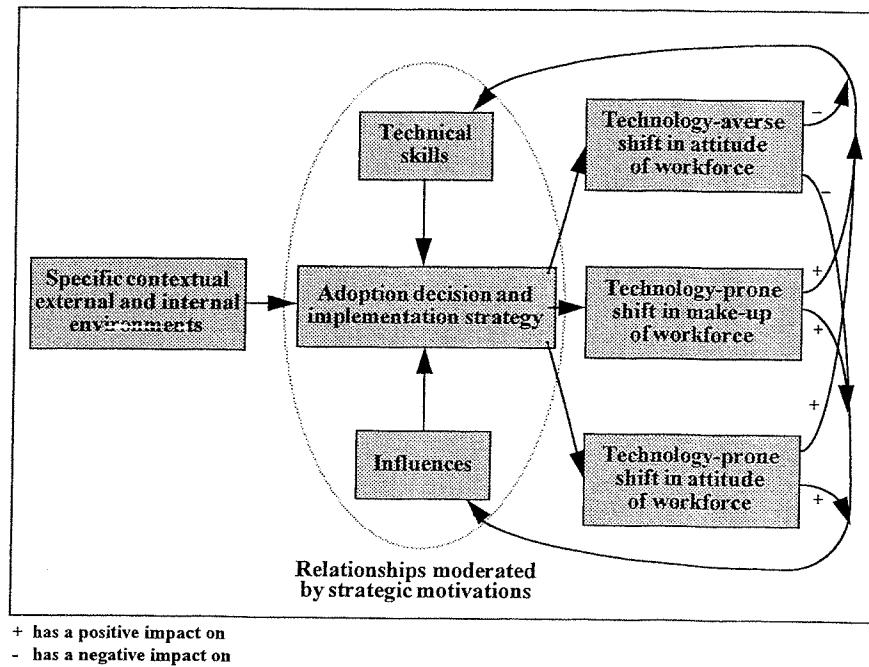
Clearly, technology gradually transforms manpower, and the very challenges involved in the

introduction of new technology change as employees are transformed. The first wave of technological change may meet with stiff resistance as fears of the unknown - i.e. deskilling and job destruction - prevail. As the reality of flexible automation sinks in, some employees whose skills (because of their age, attitude or aptitudes) could not be upgraded leave, others are trained and start growing, while yet others more qualified workers are gradually added to the workforce. Thus, the workforce as a whole may become more receptive to technological change. Indeed, the workforce may gradually be transformed from an obstacle to technological change (technology retardant), to a technology neutral factor, and even to a factor which induces further adoption of new technology.

The net impact of technology adoption on technical capabilities and employee attitude toward technological change depends on the company's strategic intent and implementation tactic. A number of field studies have shown [61] that there is no such thing as technological determinism and that the effect of technology on employees depend on how it is implemented. Figure 2 is a revised model which emphasizes the dynamics of some of the learning loops involved. Adopting a technology that fits well with the company's strategic motivation and using an appropriate implementation strategy should result in employee buy-in, and thus to increased technical capabilities and reduced resistance to the introduction of new technology. In fact, employee buy-in may even become an accelerating factor inducing more technology adoption. However, an inappropriate strategy and/or a poorly implemented technology that induce the wrong kind of learning, reduces technical capabilities through skill destruction and constitute a liability when time comes to adopt an

additional technology.

Figure 2  
A revised model incorporating a learning loop and implementation strategy



The fact that technical capabilities of blue-collar workers comes out so strong as a determinant of technology adoption in our study may be partly due to the fact that it is a proxy for the company's cumulative history of successes and failures in technology adoption. This may be our most important result. It underlines the importance of selecting and

implementing technology in such a way that employees feel that it has been a success, and are willing - even anxious - to try it again.

## **6. CONCLUSION**

The results of this study generally support the model presented in Figure 1. Intangible capabilities are determinants of further AMT adoption and it appears that strategic motivations do in fact moderate the effect of other organizational capabilities, namely technical capabilities and influences, which implies that the relationship between the different variables representing intangible capabilities is complex even in smaller firms.

The strongest determinants of the level of AMT adoption are, by far, the technical capabilities of blue-collar workers, followed by the influence of customers and vendors, and customer focussed and process improvement motivations. Thus, capabilities acquired by blue-collar workers with the use of new technologies, a reliance on external networks and a strong preoccupation with less tangible benefits, such as quality of customer services and image of the firm, constitute essential ingredients for the smaller firm hoping to attain higher levels of AMT penetration. This does not suggest that other considerations such as production costs play no role but merely that they are not exclusive preoccupations. It could be hypothesized here that organizational expectations follow an evolutive pattern moving from primarily cost-related considerations in the earlier phases of automation to the inclusion of other considerations of a less financial nature in the later stages. In fact,

financial considerations and the extensive use of cost justification techniques may be crucial as a company first decides to move into the new production technologies [4]. However, we believe that this rationale, although still quite dominant, gives way to other considerations as the firm gains experience and develops new organizational capabilities with the use and exploitation of these technologies. Firms which have succeeded in addressing these issues in the first phases of automation now try to include other types of benefits that may accrue from AMTs, namely quality of product and customer services, superior image of the firm and, increased flexibility and productivity.

It is assumed here that higher levels of automation should be promoted in SMEs. Meredith [44] has argued that smaller firms may benefit even more than large firms from the adoption of advanced technologies since these technologies enhance some of the competitive advantages a small firm is already accustomed to exploiting, namely higher quality of the products and services offered, greater customization, shorter delivery cycles, and increased flexibility in the production process. All these benefits should translate into more profitable firms, although this is not empirically investigated here.

The implications of these findings cannot be dissociated from some of the harsh realities small firms have to deal with. One such reality is the growing preoccupation with the availability of a skilled workforce. Obviously, this is a major competitive factor in today's global economy. Skilled blue-collar workers experienced with computer-based manufacturing technologies are a rare commodity. Yet, as was shown here, they are



essential if a firm chooses to invest further in the adoption of new technologies. Short-term considerations are often dominant in smaller firms, which are not as strategically articulate and long-term oriented as their larger counterparts. Thus, the presence of qualified personnel appears to be essential since time is a factor: a return on the investment must be realized within a reasonable time frame.

While the results of this study present interesting insights into the determinants of AMT penetration in smaller manufacturing firms, additional research is required to better understand the interactions between the different elements which comprise organizational assets. Longitudinal studies would constitute a next step that would allow one to uncover some of the intricate relationships that might exist between the type and level of intangible capabilities and the adoption of AMTs by SMEs. This certainly represents a potentially rich area of research for policy-makers, practitioners and academics willing to investigate the correlates of technology adoption in SMEs as well as the contributing role of these smaller firms in the overall competitive process.

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**APPENDIX 1**  
**Operational measures of strategic motivations**

Variables and their operational measures	Operational measures adapted from the following sources
<ul style="list-style-type: none"> <li>• Reduction in cost of finished product               <ul style="list-style-type: none"> <li>- reduction of inventories</li> <li>- reduction of set-up times</li> <li>- reduction of rejects</li> </ul> </li> </ul>	[47]
<ul style="list-style-type: none"> <li>• Reduction in labor costs in terms of:               <ul style="list-style-type: none"> <li>- costs of direct manpower</li> <li>- costs of indirect manpower</li> </ul> </li> </ul>	[47]
<ul style="list-style-type: none"> <li>• Increase in overall productivity in terms of:               <ul style="list-style-type: none"> <li>- productivity of direct manpower</li> <li>- productivity of indirect manpower</li> <li>- increased use of equipment and machinery</li> </ul> </li> </ul>	[45]
<ul style="list-style-type: none"> <li>• Increase in the quality of products in terms of:               <ul style="list-style-type: none"> <li>- consistent quality (reliability of products)</li> <li>- high performance products</li> </ul> </li> </ul>	[46,48]
<ul style="list-style-type: none"> <li>• Increase in the quality of customer services in terms of:               <ul style="list-style-type: none"> <li>- dependable delivery promises</li> <li>- fast deliveries</li> </ul> </li> </ul>	[46,48]
<ul style="list-style-type: none"> <li>• Superior image of the firm               <ul style="list-style-type: none"> <li>- improvement of a firm's image on the market</li> <li>- improvement of a firm's reputation</li> </ul> </li> </ul>	[45]
<ul style="list-style-type: none"> <li>• Increase in the flexibility of the manufacturing process               <ul style="list-style-type: none"> <li>- design change / introduction of new products</li> <li>- rapid volume change</li> </ul> </li> </ul>	[46,48]

**APPENDIX 2**  
**List of computer-based production applications**

Computer-assisted design (CAD) and/or Computer-assisted engineering (CAE)  
 CAD output used to control manufacturing machines (CAD/CAM)  
 Flexible manufacturing cells (FMC) or systems (FMS)  
 Numerical control machines (NC)  
 Pick and place robots  
 Other robots  
 Automated storage and retrieval system (AS/RS)  
 Automated guided vehicle system (AGVS)  
 Performed on incoming or in-process materials  
 Performed on final product  
 Inter company computer network linking plant to subcontractors  
 MRPI or MRPII

\* Adapted from a typology produced by Statistics Canada (1989)

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