HIGH TECHNOLOGY AND FLEXIBLE AUTOMATION*

Angel Martinez Sanchez

Data from Australian manufacturing industries show that high technology industries are more intensively automated that other manufacturing industries and that the technological level and product complexity of an industry are the best explanatory variables for automation intensity. The empirical evidence shows the need to modify some of the assumptions of the Utterback and Abernathy model of the innovation life cycle.

Keywords: Automation intensity, high technology, flexible manufacturing technologies, R&D, innovation life cycle, Australian manufacturing.

INTRODUCTION

The Utterback and Abernathy model of the innovation cycle distinguishes between a stage which is more oriented to product innovation and another stage which is more oriented to process innovation. Initially, when product innovation is the predominant form of innovation, there will be relatively less investment in production technology and the manufacturing process will be less integrated and more flexible. In the maturity phase, when process innovation predominates, investments in production technology will be higher, and there will be more emphasis on process efficiency, in contrast with the flexibility of the intitial stage. Various studies in the 1970s and the early 1980s confirmed empirically that process innovations appeared to be concentrated mainly in an industry's mature stage[1] whereas others like Porter[2] and even Utterback and Abernathy[3] recognized that the model does not apply to every industry.

Table 1 describes the changes that this model assumes in a firm's characteristics along its industry life cycle. In particular, the stimulus for innovation is said to change as a business matures. In the initial stage, market needs are ill-defined and can be stated only with broad uncertainty. So, great effort is expended on product design, and product innovation is rapid as competitors try to find a design that best fits the needs of potential users of a standardized product that can form the basis for rapid growth and market development as they were in the cases of Ford's model T car in the automobile industry or the VHS system in the video industry. As the dominant design catches hold in the marketplace, uncertainty about markets and appropriate targets is reduced, and larger research and development investments are justified.

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Simultaneously, process innovation - geared primarily to lowering production costs and building production volume - begin to replace product innovation as the major focus of management attention. Product changes become less frequent and less radical, and process innovation begins to get more of the R&D budget. Production systems, designed increasingly for efficency, become mechanistic and rigid, highly integrated through automation and process control; job tasks become more specialized and are subjected to more formal operating controls. At some point before the increasing specialization of the firm makes the cost of implementing technological innovation prohibitively high and before increasing cost competition erodes profits with which to fund large indirect expenses, the benefits of R&D efforts would reach a maximum. As investment in process innovation moves the production technology closer to the continuous flow end of the process life cycle, both product and process become increasingly vulnerable to the introduction of a radically new product or process technology that would make the industry obsolete.

TABLE 1
EVOLUTION PATTERN OF SOME CHARACTERISTICS ALONG THE INDUSTRY LIFE CYCLE

	Initial Stage	**Intermediate Stage**	**Mature Stage**
Competition emphasis on	Product performance	Product variation	Cost reduction
Innovation stimulated by	Information on user's needs and user's technical inputs	Opportunities created by expanding internal technical capabilities	Pressure to reduce cost and improve quality
Innovation rates	Product innovation is very high but process innovation is almost non-existent	Process innovation increases and overcomes product innovation rates	Both innovation rates diminish but process innovation still exceeds product innovation
Predominant type of innovation	Frequent major changes in products	Major process changes required by rising volume	Incremental for product and process, with culmulative productivity and quality
Product Line	Diverse, often with custom designs	Includes at least one product design stable enough to raise production volume	Most undifferentiated standard products
Production process	Flexible and inefficient; major changes easily accommodated	Becoming more rigid, with changes in major steps	Efficient, capital-intensive and rigid; cost of change is high
Equipment	General-purpose, requiring highly skilled labour	Some sub-processes automated, creating "islands of automation"	Special purpose, mostly automatic with job tasks mainly monitored and controlled
Plant	Small-scale, located near user or source of technology	General purpose with specialized sections	Large-scale, highly specific to particular products
Organizational control is	Informal and entrepreneurial	Through liaison relationships, project and task groups	Through emphasis on structure, goals and and rules

Although this is plausible for many industries, even taking into account the limits to the application of this model, it seems to suggest that less innovative firms and industries will be those which are most automated, mainly because they have a greater need for efficiency. Nevertheless, there are some recent analyses, of particular cases[4] and whole industries[5] which appear to suggest that, on the contrary, the most innovative industries invest most in automation. This apparent contradiction can be explained by the different types of automation being dealt with in each case. In a study of the automobile industry. Utterback and Abernathy described the rigid automation of the 1960s and 1970s, whereas more recent studies discuss the flexible automation of the 1980s, such as CAD/CAM, industrial robots and flexible manufacturing systems. The difference between the manufacturing systems on which the two types of automation are based is of great importance in interpreting these results, since with rigid automation, greater efficiency can only be achieved by reducing the flexibility of the manufacturing process, which could only be done by mature, less innovative industries. However, advanced manufacturing technologies enable flexibility and efficiency to be achieved simultaneously, hence the name flexible automation, and these are features which characterize innovative companies.

This paper aims to provide empirical evidence of this recently observed trend, i.e., to see whether innovative industries adopt more flexible automation technologies than mature industries. This change will have implications for the Utterback and Abernathy model and some little modifications have to be introduced to accommodate the effects of flexible automation.

HIGH TECHNOLOGY AND FLEXIBLE AUTOMATION IN AUSTRALIA

In order to give empirical support to the hypothesis in this paper, the simplifying assumptions that the innovative firms are in innovative industries, and that the innovative industries are those which can be classified as high technology industries were made. There are two criteria that are usually employed to classify an industry as high technology[6]: first, the industry must have a ratio of R&D spending to sales which is above the average for the whole manufacturing industry; and, secondly, the industry must also have a proportion of scientific and technical personnel which is above the average in the manufacturing industry. These two criteria were applied to the Australian manufacturing industries, plus a consistency criterion which means that an industry must have had ratios above average at least in two consecutive years in order to be considered as a high technology industry.

The latest year in which there are available data for both these technological criteria is 1989: there are more recent data about R&D expenditures but not about R&D personnel. The classification has been made following the ASIC three-digit level categorisation of Australian manufacturing industries. Although a classification at four-digit ASIC level has also been made it will not be used in this paper because the most disagregated data of flexible automation technologies are only available at three-digit level. Then the high technology industries in Australia are the following:

275,276 Chemical products
323 Motor vehicles & parts
334 Photographic, professional and scientific equipment
335 Appliances and electrical equipment
336 Industrial machinery and equipment

To give a more accurate picture of the high technology sector in Australia, the classification at 4-digit level shows the following industries as high-tech: 2763 (Pharmaceutical and veterinary products), 3245 (Other transport equipment), 3343 (Scientific and measuring equipment), 3352 (Electronics, computer and telecommunications equipment), 3364 (Wood and metal working machinery), 3368 (Food processing equipment) and 3369 (Other industrial machinery and equipment). In 1989 these high technology industries dedicated 11.08 per cent of their turnover to R&D and represented 6.2 per cent of manufacturing establishments, 5.84 per cent of total manufacturing employment, 4.64 per cent of total turnover, and 61.29 per cent of manufacturing firms that carried out R&D. These data indicate the small dimension of the high-tech sector in Australia but also its higher commitment to technological innovation as indicated by the R&D data and by the adoption of advanced technologies as will be shown.

The second group of data needed for the research relate to the use of advanced technologies in Australia. There are several empirical studies about the adoption of flexible automation technologies in Australian manufacturing industry but for the purposes of this paper the most suitable is the *Survey of Manufacturing Technology* carried out by the Australian Bureau of Statistics in 1988. This survey collected data on the number of items of equipment used in manufacturing establishments at 3-digit ASIC level and also collected data on the percentage of establishments that had adopted at least one equipment of each technology. A first validation of the hypothesis of the paper can be done comparing the percentages of adopters in each group of industries following the standard classification made by the OECD into high technology, medium technology and low technology industries. This analysis shows (Table 2) that high technology industries had adopted flexible automation technologies earlier and more intensively than the other industries. So CAD-CAE equipment had been adopted by 52 per cent of establishments in the high technology industries, 28 per cent of establishments in medium technology industries, and by 15 per cent of establishments in low technology industries. This pattern is also found in the other automation technologies included in the survey.

TABLE 2
ADOPTION OF ADVANCED TECHNOLOGIES

Advanced Technologies	Manufacturing Establishments High Technology	Medium Technology	Low Technology
CAD-CAE	52	28	15
CAD-CAM	18	11	6
NCMT	47	31	17
Flexible Manufacturing Systems	8	3	2
Materials working laser	4	3	2
Other advanced cutting technologies	8	12	6
Handling robots	17	11	4
Welding robots	8	5	2
Assembly robots	8	3	1
Total quality	33	28	22
JIT	29	26	19
MRP	28	21	11

Source: Own calculation based on ABS data and the criteria established by the OECD.

Another way of corroborating the hypothesis is to calculate the automation intensity of the Australian manufacturing industries as the ratio between the number of items of equipment used in an industry and the number of employees (thousands) in that industry. Even though this ratio will be used later at the industry level to explain the adoption of flexible automation, I have aggregated here the automation data for the group of high technology industries and for the other manufacturing industries. Then it is possible to compare the automation intensity of both groups of industries (Table 3). In CAD-CAE equipment the automation ratio of the high-tech industries is 6.12 against 2.01 in the other manufacturing industries which indicates that high technology industries are very automation intensive. Similarly it appears to be superior in the other technologies.

TABLE 3
AUTOMATION INTENSITY IN AUSTRALIAN MANUFACTURING INDUSTRIES*

Flexible Technologies	Manufacturing Industries High Technology	Other
CAD-CAE	6.12	2.01
CAD-CAM	1.67	0.81
NCMT	12.34	3.85
Materials working laser	0.19	0.23
Other advanced cutting technologies	1.03	0.71
Handling robots	1.80	0.78
Welding robots	1.41	0.16
Assembly robots	0.33	0.08

* High technology industries included are the 3-digit level ASIC 275, 276, 323, 334, 335 and 336. The automation intensity is the ratio between the number of items of equipment used in an industry and the number of employees (thousands) in that industry.

Source: Own calculations.

Even though the group of high technology industries at three-digit level accounts for only 23.3 per cent of total manufacturing employment, they are more representative in the adoption of flexible automation technologies (Table 4). These industries account for 73.7 per cent of welding robots, 57 per cent of assembly robots, 50.6 per cent of NCMT, 49.3 per cent of CAD-CAE equipment, 42.2 per cent of handling robots, 39.5 per cent of CAD-CAM equipment, 31.6 per cent of other advanced cutting technologies, and 21 per cent of materials working lasers.

TABLE 4
DISTRIBUTION OF FLEXIBLE AUTOMATION TECHNOLOGIES*

Per Cent

Flexible	Manufacturing Industries	
Technologies	High technology	Other
CAD-CAE	49.3	50.7
CAD-CAM	39.5	60.5
NCMT	50.6	49.4
Materials working laser	21.0	79.0
Other advanced cutting technologies	31.6	68.4
Handling robots	42.2	57.8
Welding robots	73.7	22.3
Assembly robots	57.0	43.0

* High technology industries included are the 3-digit level ASIC 275, 276, 323, 334, 335 and 336.

Source: Own calculations.

All manufacturing industries have been included in this analysis which may be seen as inadequate as these technologies are more appropriate for a particular group of industries. For example, it does not make much sense to consider the adoption of welding robots in the food industry or the adoption of materials working lasers in the chemical industry. In order to avoid this negative effect, a further analysis has been made taking into account only the metalworking manufacturing industries. These industries are included in the ASIC groups 31, 32 and 33 of which the 3-digit level high-tech industries are the 323, 334, 335 and 336. The automation intensity of these two groups of industries — high technology metalworking industries and the rest of the metalworking manufacturing industries — indicates again the superiority of the high-tech group (Table 5). In CAD-CAE equipment the automation ratio of the high-tech metalworking industries is 6.73 against 2.44 in the other metalworking industries which confirms that high technology industries are very much automation intensive. Similarly it appears to be superior in the other technologies.

TABLE 5
AUTOMATION INTENSITY IN AUSTRALIAN METALWORKING INDUSTRY*

Flexible Technologies	Metalworking Industries High Technology	Other
CAD-CAE	6.73	2.44
CAD-CAM	1.93	1.00
NCMT	14.97	6.50
Materials working laser	0.36	0.12
Other advanced cutting technologies	1.21	2.05
Handling robots	2.07	0.63
Welding robots	1.74	0.53
Assembly robots	0.41	0.09

* High technology metalworking industries included are in the 3-digit level ASIC 323, 334, 335 and 336. The automation intensity is the ratio between the number of items of equipment used in an industry and the number of employees (thousands) in that industry.

Source: Own calculations.

FLEXIBILITY ANALYSIS OF AUSTRALIAN MANUFACTURING INDUSTRY

A multiple regression analysis provides further validation of this paper's hypothesis. The dependent variable is the automation intensity (FLEX), i.e., the ratio between the number of items of equipment used in an industry and the number of employees (thousands) in that industry. As there are eight different flexible automation technologies, eight regression analyses have been made. The variables chosen to explain the automation intensity in the Australian manufacturing industry are the following:

TECH — The share of technicians and qualified personnel in industry employment. This variable is expected to explain positively the automation intensity of the manufacturing industry because a company which has a greater share of qualified personnel is more prepared to face the implementation process of a new technology and can diminish the difficulties caused by the adaptation from the old to a new production system.

CAPL — The value of depreciable assets per employee. A higher value means that the industry is depreciating more quickly the investments made in machinery and plant equipment. A higher depreciation rate allows the firm an easier financial justification for the investment in a new manufacturing technology.

SPEC — The specialization ratio which measures the degree to which enterprises coded to an industry specialise in that industry. As the adoption of flexible automation technologies enable the firm to increase the flexibility in its production process and even diversify to other activities, a negative relationship is therefore expected between the specialization ratio and the automation intensity.

COVR — The coverage ratio which is the extent to which enterprises within an industry own or control the establishments in that industry. A higher coverage ratio means a simpler managerial organization which allows a less complicated justification process for new technologies and hence a positive correlation with automation intensity is expected.

SCALE — The average size of plants (number of employees per establishment). As the flexible automation technologies included in this analysis are more suitable for medium production volumes, the regression analysis should indicate some negative relationship between automation intensity and scale.

CONF — The ratio of net surplus operating to value added which is a certain measure of confidence for the future and should make easier the justification process of a new technology. However, there are many other economic variables that influence the justification process and an economic loss does not necessarily mean that the firm should postpone their new investments because that might aggravate even more its competitiveness in the short term.

R&D — The ratio of research and development expenditures to sales. A higher ratio is expected to be positively correlated to automation intensity because if a company innovates products it must also invest in new technology to keep quality up and cost levels down.

TURN — The variation rate of turnover in the 1980s. This variable indicates the dynamic evolution of the industry. Usually the most dynamic industries are also those that invest the most in new technologies.

CONC — The concentration index of turnover of the eight biggest firms in each industry. As flexible automation technologies are more suitable for medium production volumes, the analysis should indicate a negative relationship between automation intensity and the concentration index.

COST — The ratio of wages and salaries to value added. This variable is the approximate measure of the labour costs in each industry. It is expected that the automation intensity for some technologies is negatively correlated to labour costs whereas for others it is positively correlated because the main reason to introduce automation techologies is not always labour cost savings. For example, a survey of Spanish manufacturing firms[7] found that the main reason for the introduction of industrial robots into the factories were, first, to increase technical experience and, secondly, to improve working conditions and safety.

INVEST — The ratio of plant and machinery investment to value added. Automation technologies frequently need additional investments in plant and equipment for their technical and organizational implementation and therefore a positive relationship between the two variables should be found.

WIP — The product complexity of the industry which is measured as the share of work-in-process inventories in total value of inventories. As flexible automation technologies allow more complex production activities it is expected that this variable explains positively the automation intensity in the Australian manufacturing industry.

The correlation matrix for these variables show that some of them are highly correlated and therefore should be eliminated from the analysis, e.g., R&D to TECH, and SCALE and INV to CAPL. To avoid duplication effects, R&D, SCALE and INV have been eliminated from the following explanatory model:

$$\text{FLEX} = \text{C} + \text{aTECH} + \text{BCAPL} - \text{cSPEC} + \text{dCOVR} + \text{eCONF} + \text{fTURN} - \text{gCONC} + \text{hCOST} + \text{iWIP}.$$

The results of the regression analysis (Table 6) show high values for many of the technologies which implies that the significant variables are explanatory of the automation intensity of Australian manufacturing industries. The two most significant variables are TECH and WIP, i.e., the product complexity and the technological level of the manufacturing industry. As both variables are representative and indicative of the high-tech sector, the regression analysis also validates the hypothesis of the paper. An implication of this result would be that an increase in the automation level of the Australian manufacturing industry would only be possible after improvements in the qualified personnel and a major commitment to product innovation has been made.

TABLE 6
REGRESSION RESULTS*

	CAD	CAM	NCMT	Laser	Cutting	Rob-han	Rob-wel	Rob-assem
R	0.839	0.691	0.721	0.719	0.56	0.333	0.628	0.561
F	5.541	2.128	2.52	2.504	1.064	0.292	1.521	1.07
C	-8.309	-17.372	115.992	-6.515	-8.039	-3.609	11.041	7.684
TECH	1.563	0.326	0.64	-0.057	-0.078	0.192	0.043	0.039
	(5.17)***	(1.96)**	(0.816)	(0.599)	(0.512)	(0.375)	(0.391)	(1.079)
CAPL	(0.195)	0.305	-1.735	0.095	0.131	0.162	-0.249	-0.121
	(0.409)	(1.16)	(1.402)*	(0.629)	(0.544)	(0.2)	(1.425)*	(2.132)**
SPEC	0.016	-0.008	-0.026	-0.035	0.01	-0.025	0.004	-0.0002
	(0.44)	(0.385)	(0.277)	(3.07)***	(0.547)	(0.412)	(0.793)	(0.05)
COVR	0.005	0.004	0.022	0.019	-0.038	0.049	0.0001	0.001
	(0.15)	(0.26)	(0.268)	(1.89)**	(2.42)***	(0.936)	(0.009)	(0.267)
CONF	0.036	0.177	-1.242	0.056	0.105	-0.005	-0.127	-0.076
	(0.125)	(1.103)	(1.645)*	(0.609)	(0.712)	(0.009)	(1.191)	(2.19)**
TURN	0.028	0.006	0.01	0.003	0.008	0.037	-0.007	-0.0001
	(0.949)	(0.349)	(0.131)	(0.356)	(0.539)	(0.749)	(0.661)	(0.049)
CONC	-0.019	-0.028	-0.026	0.003	0.002	-0.025	0.009	0.001
	(0.827)	(2.2)**	(0.765)	(0.462)	(0.201)	(0.649)	(1.068)	(0.246)
COST	0.099	0.237	-1.277	0.025	0.122	0.065	-0.129	-0.089
	(0.289	(1.255)*	(1.381)*	(0.87)	(0.704)	(0.111)	(1.027)	(2.179)**
WIP	0.05	-0.014	0.344	0.018	0.018	-0.065	0.048	0.01
	(1.04)	(0.525)	(2.8)***	(1.203)	(0.739)	(0.806)	(2.73)***	(1.73)**

* Figures between brackets are t-student values: 90% (*), 95% (**) and 99% (***). The statistical analysis has been carried out for the eight automation technologies: CAD-CAE equipment (CAD), CAD-CAM equipment (CAM), numerically controlled machine tools (NCMT), materials working laser (Laser), other advanced cutting technologies (Cutting), handling robots (Rob-han), welding robots (Rob-wel), and assembly robots (Rob-assem).

Source: Own calculations.

The results from the other variables are much less significant but it is worthwhile analysing them. For example, the concentration of industry seems to explain negatively the automation intensity, which means that efforts to increase the concentration level in some industries should not have substantial effects on their automation levels and maybe not on the competitiveness of the whole industry. The variable CAPL also explains negatively the automation level of the industry which means that adoption incentives should be addressed mainly to medium-size companies which have a higher proportionate use of technologies such as NCMT and robots. The variable COST explains negatively the automation level of NCMT and assembly robots which could mean that industries more automative intensive have reduced their labour costs in greater proportion than industries less automated; however, the same variable explains positively the automation level of CAD-CAM equipment which could mean that the main reason for adopting this technology was not to reduce labour costs but to increase the flexibility of the design process. The variable SPEC is only significant for laser equipment but as it is negatively correlated to the automation intensity of five technologies it is evidence that flexible automation allows further diversification of activities.

CONCLUDING REMARKS

This paper has shown the greater relative adoption of advanced manufacturing technologies by high-technology industries. Using data from the Australian manufacturing industries, empirical evidence has been given that the percentages of adopters, the automation intensity ratios, and the automation concentration ratios are much higher in the group of high-tech manufacturing industries. It has also been found that the two best explanatory variables of automation intensity in the manufacturing industries are the technological level and the product complexity of the industry which are both representative of the high-tech sector.

This empirical evidence has been aimed to corroborate some of the changes that are due to the introduction of flexible manufacturing technologies and need to be accommodated in the Utterback and Abernathy model. Flexible manufacturing technologies can substantially change the production process of the firm as they:

- increase the close interrelation between product and process innovation;
- break the trade-off between flexibility and efficiency;
- define the boundaries of manufacturing areas based primarily on process innovations;
- strengthen the trend towards manufacturing of custom-built goods on standard bases, for mass, batch and prototype production;
- demand more polivalence in the work-force, and even more flexibility

in the organization; and
- underline the relevance of technological innovation in other process areas (besides manufacturing), and in particular in information systems, as a precondition for system innovation.

Table 7 sets out the main modifications in the propositions derived by the model. A modified model for the high technology industries should acknowledge the fact that these industries adopt flexible automation technologies earlier than other industries which means that both product and process innovation follow similar patterns along the industry's life cycle instead of the differentiated pattern in the original model in which product and process innovation are almost independent. High-tech industries need to integrate product and process innovation mainly because the innovation cycle has greatly shortened in these industries. Also there is a need to modify the innovation pattern of mature high-tech industries and the original model for non high-tech industries in their mature stages since flexible automation technologies allow them to demature more quickly and maintain the process innovation rates after the intermediate stage. The discussion of the others propositions included in Table 7 — relocation of mature factories, tradeoffs, job specialization, etc — are beyond the scope of this paper but there has been some empirical evidence in the literature that suggests that the introduction of these changes in the model would better reflect real behaviour in the high technology industries.

TABLE 7
CHANGES TO BE INTRODUCED BY FLEXIBLE MANUFACTURING TECHNOLOGIES TO THE UTTERBACK AND ABERNATHY MODEL

Utterback & Abernathy model	Modified model
1) Job specialization and categories will greatly increase in the mature stage of the industry	1) Worker categories have not experienced substantial modifications but polivalence in the work-place have increased significantly. FMT is also increasing the flexibility in the work-place.
2) Factories in mature stages will relocate to areas with lower labour costs	2) The introduction of FMT, or even the direct replacement of workers will allow location of factories in medium and even high, developed economic areas.
3) Technology investment is concentrated in intermediate-mature stages	3) High technology (innovative) industries become capital intensive in an earlier stage, while older industries may demature with process innovations.
4) Cost and flexibility is an uneconomic trade-off	4) FMT have reduced the average economic production batch size.
5) Process innovation rate decreases in mature stage firms and industries	5) Process innovation rate remain high through the mature stage.

6) Production volume increases that occur in the transition stage demand important changes in the production process	6) Production volume increases may be accomplished with similar production batch sizes but with a more diverse product line which demand greater flexibility in the production process
7) Production process in the mature stage becomes very rigid by using specific-purpose automation	7) FMT diminish the rigidity of production process in the mature stage
8) Mature factories are very specialized for specific products	8) There are still specialized areas in the factory, but a more generic factory is more adaptable to an increasing variety of products lines
9) Efficiency and product line diversity cannot be achieved simultaneously	9) FMT allows both flexibility and efficiency
10) Automation inevitably produces monotonous job tasks for the worker	10) FMT allows and also demands that workers are polivalent and may do different job tasks which diminish the monotony of the automation process

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