Firm Size and the Adoption of Flexible Automation*

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ABSTRACT. Data on the diffusion of flexible automation systems in the Italian metalworking industry are used to point out the role of size for the adoption of complex, systemic innovations. Plant and firm sizes turn out to be positively correlated to adoption rates. Moreover, adoption is more likely, *ceteris paribus*, in plants which are part of large industrial groups. This pattern applies in general, and is particularly remarkable for more advanced solutions. In this light, guidelines for industrial policies that focus on financial support, the diffusion of industrial standards, and the correction of asymmetries in the availability of know-how and skills are proposed.

1. Introduction

The 1970s marked the onset of an historical phase of great instability and uncertainty in the development of world economy. Since then, the traditional "definition of success for firms" (Nelson and Winter, 1982), which relied on steadily expanding markets, cheap commodities and mass production, has proved to be no longer consistent with the new requirements of the economic environment. In particular, a demand for flexibility and for the capability of adapting production to changing market conditions has materialized.

In the short term, these developments have deeply influenced the balance of the competitive advantages of large and small firms. More specifically, they have led to the crisis of the large techno-structures, which dominated the scene in the 1960s as a result of high levels of *allocative efficiency*; on the contrary, small units have been favored, their reactive mechanisms ensuring high *adaptive efficiency*.[1]

Within this scenario of market turbulence, a set of new technological opportunities has also emerged; according to the conceptualization proposed by some authors (Freeman, 1987; Freeman and Perez, 1988; Perez, 1983 and 1985), they have given rise to a *new techno-economic meta-paradigm*, based on the low-cost inputs of microelectronics and characterized by some distinctive traits:

(a) the shift to *information intensive* rather than energy and materials intensive processes and products;
(b) the introduction of production processes which permit economies of scope to be captured and thus make possible the efficient production of a diverse range of products;
(c) the evolution of organizational structures towards the integration of functions, that enhances the ability of firms to respond dynamically to external *stimuli*.

In the sphere of production, the innovation potential offered by the application of the microprocessor to manufacturing and design technologies has been amplified by the crucial development of software packages capable of supporting highly sophisticated monitoring and control functions, and by advances relevant to automated mechanical devices and logistics. As a result, *flexible automation* (FA) has emerged as one of the most important "cluster of innovations" generated by the new meta-paradigm.

An essential characteristic of the new technology is represented by the complementary innovations it requires in a firm's organizational routines and managerial procedures; in other

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words, as will be pointed out later in detail, the adoption of FA implies the contextual adoption of a "new definition of success for firms", characterized by a new trade-off between static and adaptive efficiency and by the implementation of production strategies capable of copying more effectively with turbulent demand conditions.

This consideration has induced some authors to argue that the adoption of FA is favoured by the definition of success typical of small firms. According to such a point of view, synthesized by Piore and Sabel's "flexible specialization model" (Piore and Sabel, 1984), in spite of the traditional view about small firms towards process innovation and the evidence demonstrating the advantages of large size in the diffusion of complex technologies (see, for instance, Davies, 1979), small firms would pioneer the adoption of FA;[2] this would in turn provide them with further advantages with respect to their larger competitors and contribute in this way to a *centrifugal force* in the world economy.

The present paper is mainly aimed at testing this thesis. To this purpose, it highlights the role of *large size* for the diffusion of FA, examining attentively the various *barriers to the adoption* of the new technology as a function of the size of the adopters. Evidence consistent with the theoretical discussion, showing biases connected to both plant size and firm size and structure in the diffusion pattern of FA systems within the Italian metalworking industry, is also provided.

The empirical research underlying the paper has taken advantage of information contained in the FLAUTO database, set up at the Laboratorio di Economia dei Processi di Automazione, MIP-Politecnico di Milano. The database, currently updated to June 1987, monitors the adoption behaviour of FA systems on the part of a sample composed of about 3000 plants with at least 10 employees, representative of the Italian metalworking industry.

The structure of the paper is as follows. In Section 2, after outlining briefly the main economic features of FA technology, adoption barriers are discussed; a distinction is made between barriers connected to technical characteristics of production, and financial, knowledge and organizational/managerial barriers. In Section 3, we describe the general dynamics of diffusion, and present empirical findings that point out the influence exerted on adoption rates by plant size and firm size; the relatively higher adoption rates of plants which are part of large industrial groups are also documented. Finally, Section 4 is devoted to policy considerations.

2. Flexible automation and firm size

2.1. *The nature of the technology*

The term flexible automation (FA) generally is referred to a "cluster" of process innovations deriving from the same technological paradigm. Herein the attention is focused on FA *systems*. They are defined as integrated hardware and software, the purpose of which is to design and/or manufacture a given range of products in an automatic mode. This definition includes a set of innovations, that are characterized both by competitive relationships, as they offer technical solutions, with different levels of efficiency and cost, to similar economic requirements, and by complementary relationships originated by technological convergences and mutual learning processes.

In spite of the diversity of the various technological solutions and the degrees of freedom still available for their evolutionary development, it is possible to identify a series of characteristics shared by FA systems that influence their diffusion process.

First, let the *functional* and *sectorial pervasiveness* be considered. Potentially, FA applications span the whole range of discontinuous industrial processes and extend to every phase and function of the productive transformation — that is, design, engineering, manufacturing, assembly and logistics.

At the firm level, the pervasiveness is strengthened by the complementarities between the various spheres of application — particularly between the design/engineering of products and the subsequent transformation phases — and, above all, by the *modular* and *open* character of FA systems. Allowing to a fair extent the addition and/or the substitution of various elements and sub-systems, these latter features confer, at least potentially, to FA systems the metamorphic ability of changing their inherent structure to mold it to new requirements and market changes.

However, the level of modularity actually achieved is contingent on the diffusion of *industrial standards* relating to hardware architectures and software interfaces. On this point, uncertainty is still high due to the absence so far of a strategic agreement among the leading suppliers and to the limited experience of users. The uncertainty over standards slows down the diffusion process, for potential adopters want to avoid the danger of being locked in a "losing solution" that may force them to incur later high sunk costs. Moreover, it favours the realization of customized systems dedicated to specific users; this in turn prevents the rationalization of supply and the attainment of economies of scale in the manufacture of FA systems. The result is persistently high prices, which slow down further the diffusion process.

Secondly, the numerous innovations originated from the FA paradigm describes a *continuum* of technical solutions, from the simplest manufacturing cells to the complex FMS and to the technological frontier represented by CIM. As a consequence, a wide variety of *intermediate forms* is present, which, in exchange for a decrease of performance with respect to solutions on the technological frontier — in terms of flexibility and responsiveness to degraded operating conditions —, involve a reduction of investment costs and of the know-how required to efficiently implement and run the systems.

Thirdly, the innovation potential of FA is only partially embodied in the machinery, the devices and the software of which a flexible system is composed. To ensure high profitability for the adoption, complementary innovations, mainly in the organizational and managerial areas, become necessary. In other words, FA appears a radical *systemic* innovation.

With respect to this issue, it has been pointed out in the literature that, although the cost advantages allowed by the adoption of FA should not be neglected, more important competitive advantages lie in the sphere of market strategies.[3] Namely, FA favours the implementation of strategies that, based on non-price competitive factors, such as quality, product differentiation and diversification, and rapid "time to market", greatly influence a firm's relationships with its customer base. Yet, in order for this to be obtained, the integrated redesign of a firm's products and processes and the restructuring of considerable portions of the logistics are usually needed.

The successful adoption of FA therefore requires the acquisition of complex technical know-how relating computer based systems to integrate traditional skills in the field of mechanical technologies. Beyond that, however, the *cumulative* development of design capabilities and managerial expertise is also needed to obtain mutual adaptation between the new technologies and the structure-conduct of the adopting firm. It follows that learning processes play a central role in determining the performances of the systems and the advances of firms along the "paths of automation" towards the technological frontier.

2.2. *Barriers to adoption*

In relation to what has been argued in the previous section, it is possible to describe the main *barriers to the adoption* of FA systems — with specific reference to the more complex and advanced forms — as follows:

(a) barriers attributable to the *combined scale of production*[4] necessary to saturate FA systems. Namely, these are flexible in terms of mix of products and of its variability, but display steep short-term cost curves as the global quantity to be processed varies.[5] It is important to emphasize that firm size can reasonably be expected to be positively correlated to the adoption of marketing strategies centered on the supply of a wide range of products and the rapid innovation of the mix, such as to saturate production capacity;

(b) barriers arising from interdependencies which cause the efficiency of the installed solutions to depend to a large extent upon their functional scope and level of integration. Particular reference is made here to the *complementarity effects* between FA systems in the design & engineering, planning & control, and manufacturing spheres of activity;

(c) *financial barriers*. They are connected to the scale of the investments required, in terms of both fixed capital and costs for the training of human resources.[6] It must also be stressed that the performance of FA systems is difficult to evaluate *ex-ante*, as they depend upon correlated changes in the strategy-structure of the adopting firm. The cost of capital consequently grows in proportion to the risk of failure;

(d) *sunk costs barriers*. These refer to the high substitution costs that firms have to incur to introduce FA systems. More radical is that the greater is the technological gap on the part of the adopter, the more considerable is the depreciation of the adopter's tangible (machinery and equipment) and intangible (skills and organizational routines) assets. Such costs can be limited by introducing intermediate, technologically second-best solutions, an approach that yet involves a performance trade-off;

(e) *information and knowledge barriers*. Constraints concerning information and knowledge are to be traced to the cumulativeness and appropriability of the know-how necessary for the implementation, operation and control of FA systems. Owing to these characteristics of the technology, knowledge diffuses slowly among potential adopters, the transmission of know-how through market channels is not efficient and the possibility of relying on imitation and external learning is rather limited;

(f) *organizational and managerial barriers*. The possibility of a large-scale mobilization of technical and managerial resources is a necessary condition to accumulate knowledge through "trials and errors" processes and to carry through successfully the required adjustments between technology and internal organization.

It is interesting to distinguish between *technical barriers*, such as efficient scale of combined production, technological complementarity effects, sunk costs concerning the stock of fixed capital, and *financial, knowledge* and *organizational/managerial barriers*. The separation between these two categories appears particularly useful in a policy-making perspective. In fact, while the first barriers are very difficult to remove, being conditioned by the (largely exogenous) rate and direction of technical progress, the second type can be tackled by policy-makers, at least in theory, by providing firms with adequate financial support and positive externalities regarding the access to information, know-how and skills. What is more, in the first case the natural target of industrial policy is the supply — more specifically, the design of measures capable of stimulating suppliers to realize technical solutions matching the requirements of small scale production; on the contrary, in the second case industrial policy must concentrate on the demand side and the mechanisms of adoption.

The barriers to adoption mentioned above hinder the diffusion of FA particularly in *small and medium sized firms*. Accordingly, both the pioneering adopters and the quick imitators are to be found within *large enterprises* operating in internationalized and scale-intensive oligopolistic industries.

Namely, with respect to smaller units, such firms enjoy clear advantages connected to the cost of capital, the easier access to specific information, the availability of appropriable know-how and skills and of financial, organizational and managerial resources to devote to learning processes. Furthermore, large firms are better equipped to copy with the technological and market uncertainties that prevail also in the post-introductory phase of the diffusion process. On the one hand, the pattern of *localized search* typical of the behaviour of potential adopters (see Cainarca *et al*., 1989) is highly influenced by previous accumulation of knowledge capital and by the process innovation culture developed by them. As a corollary, smaller adopters will increasingly have recourse to *intermediate forms* of FA, characterized by less advanced computerization of monitoring and control.[7] On the other hand, owing to persistent market disequilibria, the ability to internalize the design and development of FA systems on the part of large firms proves an important factor of success.[8]

Finally, it must be stressed that the demand for flexibility originates mainly from large firms involved in mass production, subject to turbulent demand conditions. Namely, the crisis in the 1970s gave rise to a search for technical solutions allowing the "flexibilization" of production lines and the differentiation and more rapid innovation of the product mix.[9] By contrast, from this point of view, the contribution of FA to the inherently flexible definition of success of small firms[10] appears rather limited.

3. The diffusion of flexible automation in the Italian metalworking industry

3.1. *Methodology and sample of data*

The analysis of the diffusion of FA in the Italian metalworking industry is based upon the information contained in the FLAUTO database. The database concerns the adoption of FA systems and monitors a sample composed of 2927 plants to represent the Italian universe of about 25,000 plants with over 10 employees.

The empirical results presented here refer to manufacturing and design/interface systems of any complexity; they are classified in six categories, in adherence with the definitions provided in the Appendix — that is, flexible NC, CNC and DNC manufacturing systems, CAM, CAD and CAD/CAM systems. NC systems represent the bulk of the *intermediate forms* of FA.

As regards the size variables, we consider both the size of the plants of the FLAUTO sample, measured by the number of employees, and that of the firms to which the plants belong. The analysis of the adoption rates takes also account of company structure; more specifically, a distinction is made between:

(a) independent firms. This category comprises plants that belong to firms the equity capital of which is not controlled by any other firm, Italian or foreign;

(b) business groups of small or medium size (not exceeding 50,000 employees); they constitute sets of legally independent firms, connected through controlling equity linkages. This category includes, by definition, plants belonging to firms which are part of Italian or foreign industrial groups, as long as the size of these latter does not exceed the above stated threshold;

(c) large business groups (number of employees over 50,000), under Italian or foreign control. The plants in this category differ from those in the previous one because of the larger size of the controlling group.

3.2. *The general dynamics of diffusion*

Figures 1 and 2 and Table I illustrate the dynamics of the number of adopters of the various FA

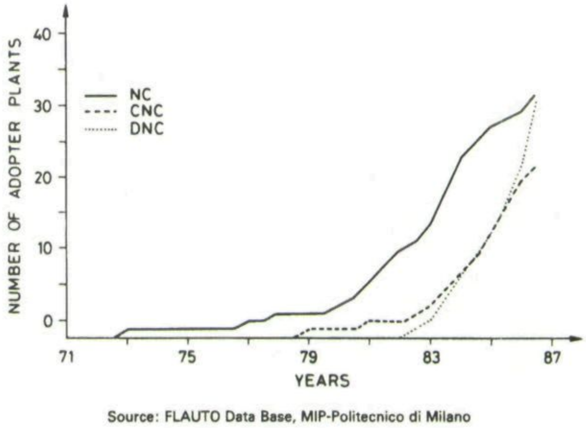

Fig. 1. Number of adopters of flexible manufacturing systems in the Italian metalworking industry (sample of 2927 plants).

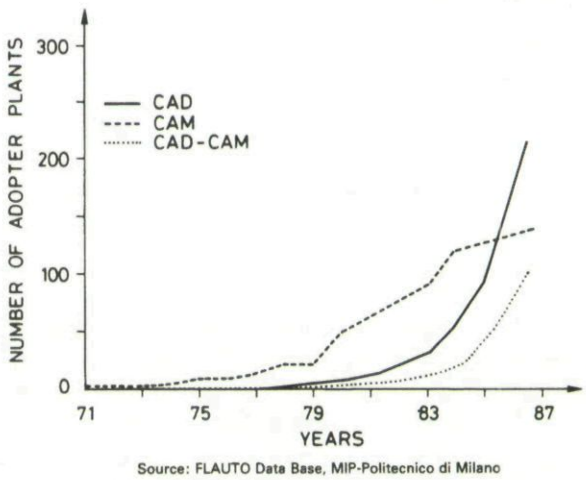

Fig. 2. Number of adopters of design/interface systems in the Italian metalworking industry (sample of 2927 plants).

systems in the FLAUTO sample, starting from their introduction in the 1970s up to June 1987.

The diffusion curves invariably show the takeoff phase at the beginning of the 1980s. Nevertheless, the growth of the number of adopters has become particularly rapid in the very last period. The number of adopters both for manufacturing and design/interface systems more than doubled in the last two and a half years. By June 1987, the incidence on the FLAUTO sample is 2.5% for manufacturing systems. With respect to the latter, design systems imply on average far smaller investments, require less appropriable know-how and expertise, are subject to a more efficient standardization process and, finally, enjoy a wider supply of external services; accordingly, by mid-

TABLE I
The diffusion of flexible automation in the Italian metalworking industry. Number of adopter plants and adoption rates on 12/31/1984 and 6/30/1987 (sample of 2927 plants)

Type of system	Adopter plants 1984 N. of plants (A)	Incidence (%)	1987 N. of plants (B)	Incidence (%)	Variation 1984—87 (B-A)/(A) (%)
Flexible manufacturing systems	33	1.13	73	2.49	121.21
NC	23	0.79	31	1.06	34.78
CNC	8	0.27	22	0.75	175.00
DNC	8	0.27	30	1.02	275.00
Design/ interface systems	162	5.53	340	11.62	109.88
CAD	54	1.84	203	6.94	275.93
CAM	110	3.76	134	4.58	21.82
CAD/CAM	19	0.65	93	3.18	389.47

Source: FLAUTO database, MIP-Politecnico di Milano.

1987 the incidence of the adopters has nearly reached 12%.

It is nevertheless useful to point out that the image of FA emerging from the FLAUTO database is rather distinct from that of completely automated and integrated factories described in CIM scenarios. On the contrary, the distribution of the number of systems installed by technological type, illustrated in Table II, suggests that, in the manufacturing area, the *intermediate forms* of FA still play a central role in the diffusion process. As of June 1987, NC systems still represented the category with the greatest weight, accounting for a 36% share of the total number of installations.

This confirms previous evidence highlighting the relevance of a step-by-step approach to adoption, that, as illustrated elsewhere by the authors (see Cainarca *et al.*, 1989), is deeply influenced by the technical and managerial profile of firms and by the amount and quality of the accumulated knowledge capital.

However, the learning processes is quite intense and is leading firms towards the adoption of more complex and advanced solutions. Namely, the analysis of the variation of the stock of installed systems (see Table II) shows that the growth rate of DNC manufacturing systems in the 1984—87 period was more than double that of the total for manufacturing systems and four times greater than that of NC systems. While CAD installations grew three times in the same period, CAD/CAMs actually quadrupled.

3.3. *The role of plant size, firm size and organizational structure*

The empirical findings relevant to the impact of plant size on the diffusion of FA are found in Table III. The table highlights, for each system typology, a systematic and significant *positive correlation* between adoption rates and the size of the adopters, a result that conforms to the evidence provided by previous studies relating to the diffusion of computer-based innovations.[11] The differences in the values are considerable, and even though marginal convergences are clear by mid 1987, the orders of magnitude remain at their 1984 levels.

In the smaller plant class, with 10 to 199 employees, the only system typology that, at the end of 1984, does not show marginal or null adoption rates (2.68%) is also the most consoli-

TABLE II
The diffusion of flexible automation in the Italian metalworking industry. Number of systems installed on 12/31/1984 and 6/30/1987 (sample of 2927 plants)

Type of system	Systems installed				Variation 1984–87 (B-A)/(A) (%)
	1984 N. of systems (A)	Incidence (%)	1987 N. of systems (B)	Incidence (%)	
Flexible manufacturing systems	79	100.00	144	100.00	82.28
NC	36	45.57	52	36.11	44.44
CNC	27	34.18	46	31.94	70.37
DNC	16	20.25	46	31.94	187.50
Design/ interface systems	183	100.00	444	100.00	142.62
CAD	54	29.51	213	47.97	294.44
CAM	110	60.11	131	29.50	19.09
CAD/CAM	19	10.38	100	22.52	426.32

Source: FLAUTO database, MIP-Politecnico di Milano.

dated one, that is CAM systems. The situation at the middle of 1987 appears partially modified, mainly due to the diffusion of CAD and CAD/CAM, with adoption rates of 3.88% and 1.88%, respectively, and of NC manufacturing systems with 0.68%. However, in accord with our expectations, adoption rates for all technological categories remain drastically below the average values of the FLAUTO sample.

The situation improves in the medium sized category (plants with 200 to 499 employees), in which the diffusion rates come relatively closer to those of the next larger class. The 1987 adoption rates, for both manufacturing and design/interface systems, are roughly half of those recorded for plants with 500 or more employees. Moreover, the behaviour of medium sized plants clearly diverges from that of small units, particularly when the more advanced systems, such as CND, CAD and CAD/CAM, are considered. The data illustrated in the table would thus suggest that the critical size threshold for the adoption of FA in the Italian metalworking industry is around 200 employees.

Table III points out also the leading role of large units for the diffusion of FA. In fact, they are characterized by mid 1987 by rather high adoption rates, with 13.61% for flexible manufacturing systems, globally considered, 35.5% for CAD, 20.12% for CAM and 15.38% for CAD/CAM.[12]

Further insights into the relationship between diffusion levels and plant size can be gained by considering the size and structure of the firms to which the plants of the FLAUTO sample belong. This also sheds light on the factors which hinder the diffusion of FA.

In Section 2.2, a distinction has been made between barriers to adoption connected to technical characteristics of production, and financial, knowledge and organizational/managerial barriers. In order to shed light on the relative importance of the two categories, it is useful to distinguish plants that are part of large business groups from those that belong to independent firms and to examine, given plant size, whether such distinctions influence adoption rates. That is, while the size of plants can be regarded as responsible for the different relevance of technical and productive constraints, the overall size of the parent company to which the plants belong can be expected to have a bearing on the height of the adoption barriers of financial nature and associated to the unavailability of organizational

TABLE III
The diffusion of flexible automation in the Italian metalworking industry. Adoption rates by plant size class on 12/31/1984 and 6/30/1987 (sample of 2927 plants)

Type of system	Plant size (number of employees) 10–199 1984 (%)	10–199 1987 (%)	200–499 1984 (%)	200–499 1987 (%)	>499 1984 (%)	>499 1987 (%)	Total 1984 (%)	Total 1987 (%)
Flexible manufacturing systems	0.52	1.36	3.08	6.18	7.06	13.61	1.13	2.49
NC	0.44	0.68	2.31	2.70	3.53	4.14	0.78	1.06
CNC	0.08	0.40	1.15	1.93	1.76	4.14	0.27	0.75
DNC	0.04	0.40	0.38	2.70	3.53	7.69	0.20	1.02
Design/ interface systems	3.20	7.64	11.15	25.87	31.18	48.52	5.52	11.62
CAD	0.60	3.88	4.62	17.76	19.41	35.50	1.84	6.94
CAM	2.68	3.36	5.00	6.18	17.65	20.12	3.75	4.58
CAD/CAM	0.28	1.88	2.31	7.72	3.53	15.38	0.65	3.18

Source: FLAUTO database, MIP-Politecnico di Milano.

resources, mangerial skills and know-how. Given plant size and similar operating conditions, we would therefore expect higher adoption rates for units that belong to large industrial groups.

The results of the previous analysis, carried out in adherence with the classification of firm structure proposed in Section 2.1, are presented in Tables IV and V, for manufacturing and design/interface systems, respectively. They clearly support the argument that large industrial groups provide plants with positive externalities which favour the adoption of FA systems. That is, for each plant size and technological typology (with the only exception of flexible manufacturing systems for medium sied plants), plants which are part of industrial groups show higher adoption rates than those which belong to independent firms. The pattern is particularly remarkable for small units; in this size class, the adoption rate of the plants which are part of industrial groups is 3 times greater than that of plants of independent companies. The relationship holds true for both manufacturing and design/interface systems, with ratios equal to 3.0 and 3.2 respectively.

The gaps between adoption rates as a function of firm structure generally decrease as the size of plants grows, even though the trend is not homogeneous for all technological categories. In particular, as far as manufacturing systems are concerned, the difference between the adoption rates of the two categories — industrial groups and independent firms — is very high also for large plants; the ratio between the two rates reaches a value of 2.2, far higher than those found both for manufacturing systems in medium sized plants (in which, with a ratio equal to 1, the difference between the two categories disappears) and for design/interface systems in large plants (ratio equal to 1.2).

Finally, the distinction between large and small/medium sized business groups is also quite interesting. Generally speaking, the differences between the adoption rates of independent firms and those of *large* groups are more evident as compared to those between the former and industrial groups as a whole. Namely, adoption rates in the large groups category exceed those in the small groups category for each plant size class and technological typology (with the exception of design/interface systems for small plants). The phenomenon is particularly remarkable for manufacturing systems.

TABLE IV
The diffusion of flexible manufacturing systems in the Italian metalworking industry. Adoption rates by organizational structure and by plant size class (sample of 2927 plants)

Plant size (number of employees)	Independent firms (A)	Industrial groups (a) Total (B)	< 50,000 (C)	> 50,000 (D)	Total	Ratio between rates (B)/(A)	(D)/(A)
10–199	1.21	3.63	2.72	6.88	1.36	3.00	5.69
200–499	6.87	6.73	4.68	10.63	6.18	0.98	1.55
>499	6.46	14.43	10.93	17.39	13.61	2.23	2.69

(a) Subdivided by number of employees.
Source: FLAUTO database, MIP-Politecnico di Milano.

TABLE V
The diffusion of design/interface systems in the Italian metalworking industry. Adoption rates by organizational structure and by plant size class (sample of 2927 plants)

Plant size (number of employees)	Independent firms (A)	Industrial groups (a) Total (B)	< 50,000 (C)	> 50,000 (D)	Total	Ratio between rates (B)/(A)	(D)/(A)
10–199	6.74	21.51	24.23	12.16	7.64	3.19	1.81
200–499	18.15	35.40	31.69	42.62	25.87	1.95	2.35
>499	41.26	50.28	43.68	55.78	48.52	1.22	1.35

(a) Subdivided by number of employees.
Source: FLAUTO database, MIP-Politecnico di Milano.

Overall, it clearly turns out that technological factors are not sufficient to explain the differences in adoption rates pointed out by the analysis of the FLAUTO sample. Even after taking account of technological constraints directly connected to the scale of operations and to other characteristics of production, there still remain wide differences in adoption rates. These seem to be for the "business group" an important determinant.

A likely explanation for this result resides in the greater availability with respect to smaller independent firms of tangible and intangible assets necessary for the successful introduction of FA systems. In this perspective, a central role is certainly played by *financial resources*, because of the amount of the investments involved and the high (*ex-ante*) uncertainty regarding the performance of the systems. This argument applies specifically to flexible manufacturing systems, which, when compared to design and interface systems, usually require far higher investments and are subject to more uncertainty as regards the *ex-ante* evaluation of performances. For the technology business group, organizational structure turns out to have a large, positive effect upon adoption rates.

However, the gaps in the adoption rates of design/interface systems, in which limited investments are now possible, remain sizable. This fact supports the thesis that *organizational/managerial* factors and *access to know-how* also play a decisive role for the acquisition and implementation of FA systems.

The findings of our analysis confirm the complex, systemic and cumulative character of FA technologies. They point out the advantages of large size for the adoption of innovations of this sort; these derive mainly from the availability of a wide *spectrum* of internal diversified resources, financial, managerial and technical, from the more immediate access to the results of technical progress not embodied in capital goods, and, finally, from the presence of "internal laboratories" for the fine-tuning and incremental innovation of the applications of advanced technologies.

4. Guidelines for industrial policy

The rapid growth of the number of FA systems installed in the last years in the Italian metalworking industry is not to be interpreted as the result of a 'canonic' diffusion process, such that a successful innovation with consolidated features and performances substitutes progressively an old, no longer competitive technology. Instead, the process is still in a *transition* phase, marked by continuous innovations, which improve incrementally the basic paradigm, by open competition to set up the 'winning solutions', and by uncertainty and market disequilibria.

As a consequence, the investment criteria of potential users conform to a *step-by-step approach* to adoption based on learning through experience and on the 'localized search' for solutions consistent with the stock of technical and organizational expertise accumulated by firms.

In this perspective, the findings illustrated in the previous section show the persistence of a remarkable gap in adoption rates in favour of large size. The evidence provided suggests some policy considerations aimed at trying to re-balance the pattern of diffusion. Even though they focus on FA systems, they apply more generally to the diffusion of complex and systemic innovations.

The first considerations concern policies that provide firms with financial incentives — such as subsidies, low interest loans, other credit facilities, tax incentives and so on. The removal of financial barriers still remains a key priority to fuel the diffusion of new technologies among small and medium sized firms. Yet, incentive policies should take into account the rapid evolutionary dynamics of advanced production technology; this implies a high level of flexibility as to the criteria and the administrative procedures for allocating resources.[13]

A second set of considerations focuses on the *standardization* issue. This question is extremely important for the whole European industry, which, as regards the diffusion of industrial standards, actually lags far behind Japan and also the United States. The problem must be dealt with at the EEC institutional level, in agreement with and with the active cooperation of the suppliers of FA components and systems and of the main users in the various countries. A large-scale policy program is needed to foster the definition and diffusion of 'open' standards, similarly to what has been achieved for the Open System Interconnection. Particular attention must be devoted to the problem of modularity and to the possibility of retrofitting equipment.

The advances in this field constitute an essential contribution on the part of policy-makers to the diffusion of FA, specifically for small firms. This is for a number of reasons. First, standardization enables economies of scale and of rationalization to be captured by suppliers, thus reducing capital investment costs for the adopters. Second, and even more important, it creates a reliable frame of reference for users. In fact, it allows them to implement gradual investment strategies in modular systems and intermediate forms of FA that can be integrated later into more complex architectures, through physical, logical and functional interfaces. This step-by-step approach reduces costs and adaptation times, and minimizes the depreciation of physical equipment, know-how and specialized skills.

The last series of policy considerations is stimulated by the role, highlighted by the empirical analysis, of large industrial groups in decreasing the height of adoption barriers. From this point of view, the industrial group can be viewed as an "environment" providing individual units with innovative *stimuli* and tangible and intangible support to the adoption of new technologies. The greater efficiency of its endogenous mechanisms with respect to the market — that is, with respect to the natural environment of independent firms —, witnessed by the data, suggests that policy makers have wide margin to promote the diffusion of FA technologies within the set of small and medium firms. These consist primarily in the correction of market imperfections, by reproducing on a widened scale the positive externalities available within the group.

The difficulty of the exogenous and diffused generation of those factors of success are not to be overlooked. They are to be traced firstly to the high appropriability of tacit technical and managerial knowledge, and to the difficulty of external imitation and learning. Secondly, an efficient interaction with complex economic, social and institutional systems is required, in order to:

(a) organize the systematic supply of information on the results of technical progress generated by the international scientific and industrial community, to make them accessible to all potential users;
(b) deal with the problem of training human resources to various levels of competence and functional roles. This is necessary to overcome the serious hiring difficulties that firms — and particularly small firms [14] — are experiencing in the present transitional phase;
(c) provide services capable of supporting the introduction, implementation and management of systemic innovations, by favouring the diffusion and adaptation of experience developed in more advanced environments.

APPENDIX

a. *Flexible manufacturing systems*

These are systems consisting of at least two machine tools connected by means of automatic material handling devices; at least one numerical control (NC) machine is present. The type of NC equipment and the 'quality' of the coordination between the various equipment determines the level of flexibility.

- NC manufacturing systems: they include at least one NC, but there is no data coordination among the various machines. In other terms, the system does not include microprocessors or computers, or, if included, they exclusively oversee to the operations of a single machine. System 'intelligence' is therefore limited. Furthermore, reconfiguration of the system involves long set-up times.
- CNC manufacturing systems: the NC of the various machine tools and/or of the material handling devices are also responsible for the automatic coordination of the system. Reconfiguration is possible *via* software, though within a limited range of applicability.
- DNC manufacturing systems: these are characterized by a hierarchical computer architecture; a host computer controls the activities of several machines and material handling devices. Reconfiguration is possible *via* software in a considerably larger range than that of CNC systems.

It is worth stressing that the degree of system complexity is evaluated in terms of computer-driven coordination and control and of reconfigurability, rather than in terms of number of machines, as proposed in most previous studies.

b. *Design and design/interface flexible systems*

- CAD systems: computer aided systems, the functions of which span from simple drafting, to the more complex design and engineering tasks.
- CAM systems: computer aided systems for the generation of part-programs used by NC machine tools. In some applications, they also carry out complex control functions within the production process.
- CAD/CAM systems: computer aided systems that integrate by means of a central database the functions separately carried out by CAD and CAM.

Notes

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[1] A discussion of the notions of allocative and adaptive efficiency, with particular reference to the characteristics of flexible automation technologies, can be found in Colombo and Martiotti (1985).

[2] The argument that FA is more conducive to small rather than large firms is clearly illustrated by Diwan (1989) in a recent issue of this Journal. "Since FM (Flexible Manufacturing) requires that production is in small batches and because customer satisfaction is quite important, small firms have a distinct advantage. On the other hand, large sized firms have a clear disadvantage insofar as they have to write off the cost of existing capital and unlearn the old habits and ways of organizing production".

[3] See among others Jelinek and Goldhar (1984) and Voss (1985).

[4] The term "combined scale of production" refers here to the sum of the scale of production of the different products processed by a given system.

[5] Following the definition proposed in Colombo and Mariotti (1985), FA systems can be considered as 'inelastic'.
[6] This point is widely documented in the managerial literature. See for instance Bessant and Haywood (1985) and Hollard *et al.* (1986).
[7] These forms, which take on a relevant role in the first stages of diffusion (see again Cainarca *et al.*, 1989), have been inexplicably neglected by most studies dealing with FA.
[8] Some authors (for instance, Meredith, 1987; Freeman, 1987) have argued that the efficient utilization of FA technologies can become inhibited by the rigid divisionalization and specialization of tasks typical of the organizational culture of large firms, and is stimulated instead by horizontal flows of information. This should increase, *ceteris paribus*, the likelihood of successful adoption on the behalf of smaller firms. It must nevertheless be noted that such observations are suggested by the examination of the international competitive arena of oligopolistic industries. In such a context, the notion of 'small firm' drastically differs from the one employed in the present paper.
[9] A discussion of this argument can be found in Colombo and Mariotti (1985).
[10] As a wide body of research has pointed out, such definition of success relies largely on organizational factors, such as the responsiveness of non-bureaucratic organizational structures, the scarce unionization of the work force, etc., rather than on technological factors.
[11] For instance, Northcott *et al.* (1985) show that the diffusion rates of microelectronics both in product and process innovations, in France, Germany and United Kingdom, increase abruptly with firm size. Moreover, according to Kelley and Brooks (1988), in the U.S.A. small firms (i.e., firms with less than 20 employees) account for a significantly larger share of 'non adopters' of programmable automation than of 'active adopters'.
[12] In order to check for possible sectorial biases, the analysis has been replicated for each macro-sector composing the metalworking industry (primary metal and metal products, mechanical engineering, electrical and electronic products, transportation equipment, and precision instruments). For each sector, the pattern replies the one described here and confirms the leading role of large plants.
[13] For instance, the policy implemented to the purpose in Italy up to mid 1987 — specifically, the law n. 696, December 19, 1983 — did not contemplate financial support for software and training expenses. Only recently, the law-decree n. 212, June 1, 1987, has broadened the area of intervention to include them.
[14] This issue is addressed in Bessant and Haywood (1987).

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