Technological Regimes and Innovation: Looking for Regularities in Dutch Manufacturing

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Abstract

This paper explores the characteristics of 'technological regimes' in Dutch manufacturing. Using evidence from the second Community Innovation Survey (CIS-II) a classification of technological regimes that refines Pavitt's taxonomy is tested. Significant differences across regimes emerge with respect to a variety of dimensions: (i) the level and persistence of technological opportunity, (ii) the sources of technological opportunity inside and outside the firm – including formal collaborations – and (iii) the specific trajectories along which new opportunities for innovation are exploited. Our results confirm the usefulness of the concept of a technological regime as an analytical framework to "interrogate" large databases and to find empirical regularities relevant for the development of a (sectoral) theory of innovation.

Key Words: innovation; technological regimes; industry studies

JEL Codes: O31, O33, L60

1. Introduction

Aim of this paper is to give further insight into the characteristics of technological regimes by using data from the second Community Innovation Survey (CIS-II) of Dutch manufacturing.[1] The concept of technological regime has been introduced by Nelson and Winter (1977 and 1982) as an "intellectual framework" for interpreting the variety of innovative processes observed across industrial sectors. Technological regimes draw a link between the various aspects of the innovation process and organize inter-industry differences into a few invariant categories. Such a framework, Nelson and Winter argued, is important for the theoretical understanding of innovation; this, to be useful for the policy debate, has to take into account the diversity of the "institutional structure" (and in particular for our purpose the nature of technologies) relevant for innovation. In particular, Nelson and Winter suggested a model of technological regimes that distinguishes between a "science-based" case and a "cumulative technology" case.

In this paper, we use the classification of technological regimes proposed by one of us (Marsili 2001) as a refinement to Pavitt's taxonomy. It distinguishes five regimes: science-based regime; fundamental processes regime; complex systems regime; product-engineering regime and continuous processes regime. The analysis has two purposes: to test the robustness of the classification for the case of Dutch manufacturing and to expand the number of properties of technological regimes that can be explained by such a classification. The following main dimensions of technological regimes will be addressed: (i) the properties of innovative processes; (ii) the sources of technological knowledge in an extended definition including the various internal functions of the firm and forms of collaborations; and (iii) the

[1] The empirical part of this research has been carried out at the Centre for Research of Economic Microdata (Cerem) at Statistics Netherlands. The views expressed in this paper are those of the authors and do not necessarily reflect the policies of Statistics Netherlands.

factors inducing innovation along selected technological trajectories. The analysis shows that by using the new classification of regimes it is possible to explain significant levels of variations in these dimensions for Dutch manufacturing sectors. A richer description of technological regimes is thus outlined as a result. This confirms the usefulness of the concept of a technological regime as a framework to "interrogate" large databases and to find regularities in the properties of innovation processes.

Section 2 of the paper explores the concept of technological regimes in the literature and outlines the dimensions that are relevant for our empirical investigation of regimes. Section 3 describes the method of study. Section 4 reports the findings of the empirical analysis and Section 5 is the conclusion.

2. Context and background

The notion of a technological regime is concerned with the technology upon which firms rely in their problem solving activities, given a broadly defined way of doing things (Nelson and Winter 1977). As Nelson and Winter stressed their concept is of a cognitive nature, "relating to technicians' beliefs about what is feasible or at least worth attempting" (1977, p.57). A technological regime sets the boundaries to what can be achieved in the problem solving activities associated with a given set of production activities, and the directions ("natural trajectories") along which solutions are likely to be found. A technological regime thus guides technicians, engineers and scientists involved in innovative activities towards developing and employing certain heuristics, tactics, and objectives to solve a particular problem (Nelson and Winter 1977, 1982).

Dosi (1982) developed further the definition of technological regimes and technological (or "natural") trajectories, by suggesting that a technological regime can be characterised with respect to a number of fundamental dimensions: (i) the properties of the learning processes associated with the firm's problem solving activities; (ii) the system of sources of knowledge, internal and external to the firm, relevant for such problem solving activities; and (iii) the nature of the scientific and technical knowledge base upon which firms draw in solving problems. Dosi (1982) also argued that the concept of technological regime is useful to solve the old distinction between demand-pull (or market-driven) and technology-push (or technology-driven) innovations (see Kline and Rosenberg, 1986). This is because technological trajectories of different character (falling in one or the other category) can prevail in different regimes or in different stages of the evolution of a regime.

The broad "cognitive" definition of a technological regime given by Nelson and Winter has been further operationalised with regard to the dimensions suggested by Dosi (1982). A technological regime is then identified in terms of the specific combination of technological opportunity conditions, appropriability conditions, cumulativeness of learning and nature of the knowledge base (Dosi 1988; Malerba and Orsenigo 1993). Accordingly, the properties of the learning processes are described by the ease with which new or improved solutions to problem solving activities are found (level of technological opportunity); the ease with which such solutions can be protected from imitation (degree of appropriability); and the extent to which the discovery of new or improved solutions build on previous results (cumulativeness). In the definition above, the system of sources of knowledge specific to a regime contributes to define the technological opportunity conditions in terms of both the general level and structure (Winter 1984). These sources include the various internal functions of the firm (for example, R&D, production, marketing), other firms in vertically related industries (buyers and suppliers), competitors, and institutions outside the industrial system, such as universities or (semi-)public research labs.

Last, the nature of knowledge in the definition of a technological regime expresses the extent to which knowledge is tacit versus codified; specific versus pervasive across problem solving activities; simple versus complex; independent versus element of a system (Winter 1984). The nature of knowledge influences the specific forms that the transfer of knowledge within the firm or from external sources assumes in a regime. Fully codified knowledge is, by definition, easily transferred, for example through journal articles or patents. In contrast the transfer of tacit knowledge is indirect and personnel embodied; it may involve informal contacts, contract research as well as long-term collaborations (Malerba and Orsenigo 1993). In addition the transfer of systemic knowledge, which is element of a broader interdependent system, may require cooperative arrangements with the sources involved (Teece 1986).

The basic model of technological regimes is that proposed by Nelson and Winter (1982). It distinguishes between a "science-based" technology and a "cumulative" technology. The former is characterised by a broad and universal knowledge base, which comes from externally (often non-private) performed intense R&D activity. The latter is characterised by a rather narrow and targeted knowledge base, which is cumulatively built through the learning processes inside the firm. This model has been used to establish a relationship between technologies, patterns of innovation, and industrial competition. Nelson and Winter (1982) and Winter (1984) showed through formal modelling that the above model of technological regimes leads to distinct patterns of innovation and industrial competition. Specifically, a "science-based" technology favours the innovative entry of new firms with respect to the innovation of established firms, that is, an "entrepreneurial" pattern of innovation. In contrast, a "cumulative" technology favours the innovation of (large) established firms, while the opportunities for outsiders are rather limited, that is, a "routinised" pattern of innovation.

Various authors have empirically tested Nelson and Winter's model of technological regimes by looking at the differences across technologies and industrial sectors in patterns of innovation and competition. In an empirical study of European patents Malerba and Orsenigo (1996) used the concentration of innovative activities (across firms), the rate of innovative entry, and the stability over time of the hierarchy of major innovators, based on the number of patents, as indicators of the patterns of innovation in different technologies (patent classes). They found that distinct patterns of innovation, with characteristics similar to the "entrepreneurial" and "routinised" patterns, and labelled as 'Schumpeter Mark I' and 'Schumpeter Mark II', emerged in two distinct groups of technologies. The two groups were relatively invariant across the six (advanced) countries examined.

In a more recent study, Breschi, Malerba and Orsenigo (2000) examined the relationship between Schumpeterian patterns of innovation and the characteristics of technological regime. These were expressed in terms of technological opportunity, appropriability and contribution of science (as an indicator of the universal versus specific nature of knowledge). The results showed a non-linear relationship between Schumpeterian patterns of innovation and the relevance of science for innovation. This would suggest a more complex characterisation of technological regimes than implied by Nelson and Winter's model.

Other empirical studies have started to explore the relationship between Schumpeterian patterns of innovation and patterns of industrial competition. For example in Dutch manufacturing, Van Dijk (2000) found on average statistically significant differences of structures (for example, market concentration) and performance (for example, profits margin) between industries classified into a Schumpeter Mark I group and a Schumpeter Mark II group according to Malerba and Orsenigo's definition. However, differences were not (or less) significant when dynamic indicators of competition were used, such as the turnover of firms (entry and exit rates) and the mobility in market shares of continuing firms. In addition, significant differences were observed with respect to a third group of industries, which could not be classified into either one of the ‘Schumpeterian’ groups.

While these studies provide useful insights into the importance and significance of the concept of technological regimes, we feel that they also show the limitations of a distinction into only two alternative regimes. Such a dichotomy may indeed be too narrow a view in light of the large empirical variety in technological performance and properties of innovative processes. For example, it does not account for differences in opportunity conditions as both low and high levels of opportunity can underlie each regime (see the above discussion of the Breschi and Malerba, 2000 results). Also, Van Dijk (2000) found that there is a group of industries in Dutch manufacturing that is not easily fit into either category of the Schumpeterian dichotomy.

Pavitt’s taxonomy of the organisational and structural traits of innovative firms appears more useful in this respect (Pavitt 1984). Pavitt’s model focuses on the determinants and directions of technological trajectories. The latter are distinguished into cost cutting and product design. The former are identified in the sources of technology (suppliers, R&D, public science and so on), the type of user (price versus performance sensitive) and the means of appropriation (such as patents, secrecy, technical lag and so on). The classification was then tested by using data on innovation counts from the SPRU innovation database. The properties of innovation patterns empirically examined concerned: (i) the role of firm size, measured by the size distribution of innovative firms); (ii) the system of sectoral interdependence in innovation, expressed by the input-output matrix of the sectors of origin and use of innovation; and (iii) the relative balance between product and process innovations. Although Pavitt’s taxonomy does not refer directly to the definition of technological regimes as illustrated above, it can be related to the conditions of technological opportunity, threat of technology-based entry[2] and appropriability (Pavitt, Robson, and Townsend 1989). However, the classification is not based on the consideration of the knowledge base of the firm[3]. Pavitt's taxonomy has been tested empirically using innovation surveys, for example by Archibugi, Cesaratto and Sirilli (1991), Cesaratto and Mangano (1993), and De Marchi, Napolitano, and Taccini (1996).

The classification used

In this paper, a new typology of technological regimes is used, which refines Pavitt's taxonomy (Marsili 2001). The typology of regimes was derived as a summary of the empirical evidence from a combination of data sources (patents, R&D statistics, scientific inputs, innovation surveys, and so on). In particular, evidence was drawn from the SPRU database on the world's 500 largest firms, US R&D statistics, and the PACE report on the technological opportunity and appropriability conditions of European firms. Indicators for a number of variables were examined. The nature of the knowledge base was defined in terms of the distribution of technological activities (patents and R&D personnel) across different fields of knowledge (falling into the broad categories of chemical, mechanical, electrical-electronic technologies) and the degree of complexity (diversification) of such a knowledge base. The properties of innovative processes were expressed by the level of technological opportunity; the level of technological entry barriers – that is, the ability of new firms to access and exploit new knowledge relevant for innovation – as a function of the specificity of knowledge and scale-related advantages in knowledge accumulation; and the degree of cumulativeness. In

[2] The concept of threat of technology-based entry differs here from that of appropriability. The former concerns the advantage of an innovator with respect to new firms from outside an industry; the latter concerns the advantage of an innovator with respect to all the other firms, either within or outside an industry.

addition the degree of inter-firm diversity in the exploitation of technological opportunities (for example in R&D intensity) was considered as a further property (see Malerba and Orsenigo [1993]). The sources of knowledge were characterised by the contribution of external sources and, in particular, of academic research. Technological trajectories were only in part reflected by the relevance of product and process innovation. The classification distinguishes five regimes.

The *science-based* regime characterises innovative activities with a knowledge base in ‘life’ science and ‘physics’ science. This regime, typical of in pharmaceuticals and electrical-electronics industries[4], is characterised by high general levels of technological opportunity and ‘technological richness’ (that is, because of the universal nature of scientific knowledge technologies enable these industries to generate a continuous stream of new products), high technological entry barriers originating in the high specificity of knowledge applications across production processes, and high cumulativeness of innovation. Firms are homogeneous in their rates and directions of innovation, which are focused on closely related technologies. Innovative activities are principally devoted to product innovation and benefit from the direct contribution of scientific advances in academic research.

The *fundamental-processes* regime, associated with chemistry-based technologies, in chemicals and petroleum industries, displays a medium level of technological opportunity, high technological entry barriers especially related to scale advantages in innovation, and strong persistence of innovation. Innovation is mainly process innovation and, although affiliated firms and users represent the main external sources of knowledge, it benefits from the quite important and direct contribution of scientific advances in academic research.

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[3] Pavitt, personal conversation.
[4] This group also comprises the photography and photocopy industry, which in the standard industrial classification falls within the instruments sector.

The *complex (knowledge) system* regime presents a knowledge base that combines mechanical, electrical/electronic and transportation technologies. This regime, in aerospace and motor vehicles industries, is still characterised by medium-high levels of technological opportunity, entry barriers in knowledge and scale, and persistence of innovation. The distinctive feature of this regime is in the high degree of differentiation of technological competencies developed by firms, especially in upstream production technologies, and of external sources of knowledge, including an important, although indirect, contribution of academic research.

The *product-engineering* regime, which relies on mechanical engineering technologies, is characterised by a medium-high level of technological opportunity, low entry barriers to innovation and not very high persistence of innovation. This regime, which represents in particular non-electrical machinery and instruments[5], is distinguished by the high diversity of technological trajectories explored by firms. Innovation is in products and benefits from external contributions of knowledge, mainly from users.

Lastly, the *continuous-processes* regime includes a variety of production activities such as metallurgical process industries - metals and building materials, chemical process industries – textiles and paper, food and tobacco. The knowledge base is distinguished by the combination of chemical/metallurgical processes with mechanical/electrical technologies (the latter related to production processes). This regime is generally characterised by low technological opportunity, low technological entry barriers, and rather low persistence in innovation. Firms are technologically heterogeneous and their knowledge base is, on the whole, fairly

[5] As part of the instruments sector, the product-engineering regime includes machine controls, and electrical and mechanical instruments, while it excludes the photography and photocopy industry. Fabricated metal products and rubber and plastic products are also classified under this regime.

differentiated among technical fields. Innovation in processes benefits from upstream sources of capital-embodied knowledge.

With respect to Pavitt taxonomy, the classification distinguishes industries with a chemistry-knowledge (fundamental processes regime) base from those with a life-science knowledge base (pharmaceuticals in the science based regime). In addition, the aerospace and motor vehicles industries are distinguished for the complexity of the underlying knowledge base. A group of industries with a knowledge base in chemical and metallurgical processes is also defined which include industries with different attributes in Pavitt taxonomy (See Appendix A for list of industries and regimes).

3. Method

Two approaches can be followed in testing a taxonomy. One is inductive and consists in carrying out a clustering exercise on a specific dataset with no precedent notion and then compare the outcomes with the taxonomy in consideration. For example, Archibugi, Cesaratto and Sirilli (1991), and Cesaratto and Mangano (1993) have followed this approach, by using the data from the Italian innovation survey. They found that Pavitt's taxonomy was confirmed with some minor differences and then they provided their refinements to the taxonomy. Clustering offers a useful technique to compare an established taxonomy with groups of observations similar on a selected set of characteristics. However, its results are specific to the database and indicators used, and the boundaries are likely to change from one exercise to another. Without the reference to a broad pre-existent theory it becomes then difficult to establish the reasons why some observations have fallen into a class rather than in another.

Another approach is more deductive and consists in applying a given taxonomy to test whether the data fit the theory of innovation expressed by the taxonomy. Examples of this use of Pavitt's taxonomy and the OECD classification can be found in the studies of De Marchi, Napolitano, and Taccini (1996) and Laursen and Meliciani (2000). This approach seems to respond better to the development of a theory, in which taxonomies are used as tools to search for empirical regularities independent of the databases and indicators used. The focus is more on the understanding of the mechanisms through which a certain classification emerges than that of examining the specific traits and structure of the classification itself.

At this stage of development of the classification, which was derived from the evidence referring to specific (and sometime limited – for example to large firms) data sources and indicators (such as, R&D and patents) we follow the second approach. This responds to our purpose of testing whether the classification holds for a different country (the Dutch manufacturing) and a richer dataset (the innovation survey) and of establishing whether the classification can be usefully applied to find regularities in other properties of the innovation process, not initially considered.

3.1 Data and structure of the test

Empirical taxonomic exercises of the patterns of innovation have focused on the structure of innovative firms in an industry, such as firm size, (Pavitt 1984) and their dynamics in different technologies, such as innovative entries and exits (Malerba and Orsenigo 1996, 1999). In contrast, the focus of this analysis is on the underlying processes through which innovative knowledge is acquired and developed, that is, on the dimensions of a technological regime.

In the analysis, we use micro data on innovation from the second Dutch Community Innovation Survey (CIS-2) carried out by Statistics Netherlands. The survey was held in the entire private sector for firms with at least 10 employees and covers the years 1994-1996. In manufacturing, a total of 3299 responses were obtained with a response rate of 71 per cent.

This sample is representative of a population of 10260 firms of which 6069 are innovators. In addition we use data on the composition of (outsourced) R&D expenditure from the R&D survey, available for a subset of firms representing about the 16 per cent of the sample.

The innovation survey database enables us to measure the characteristics of technological regimes through a multitude of indicators. With respect to the variables that were used for the definition of the classification, it is possible for example to overcoming the problems associated with the exclusive use of R&D and patents as a measure of technological activity. In addition, aspects of the cumulativeness of learning related to the organisational structure of innovative activities (for example in permanent R&D labs) at the level of the firm can be captured from the survey. This also allows us to give a richer description of the sources of innovation, by expanding the analysis to the in-house functions of the firm and the role of collaborations with external sources. Finally, technological trajectories can be characterised not only in terms of the balance between product and process innovation, but also of a set of the driving forces of innovation.

The empirical test of technological regimes is carried out at the level of industrial sectors. For each firm, the line of business at 6-digit level according to Statistics Netherlands' standard classification of industries as of 1993 is available. In order to obtain a sufficient number of observations within each sector, we aggregate these lines of business into 62 sectors, ranging between 2- and 4- digit level, each one allocated to a technological regime, as illustrated in Table I of the Appendix.[6]

We then estimate indicators of innovation at the level of sectors by weighting individual responses of a factor stratified by SIC 2-digit sector, size class and region, which is

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[6] Because of the high degree of product diversification, some firms could not be classified into any of the 62 sectors. For this reason, 13 responding firms were excluded from the analysis.

constructed by Statistics Netherlands to account for sampling biases of the population. Accordingly, from the survey sample it is possible to generate estimates that refer to the overall population from which the sample was drawn. All the indicators used in this paper are therefore estimated values for the total population of manufacturing firms.

In order to assess whether technological regimes significantly contribute to explain cross-sectors differences in innovative patters, T-tests of the means over sectors between each combination of regime are carried out.

3.2 The variables

In testing our hypotheses, we take into account a broad set of indicators of innovative activities, spanning the entire innovation survey. We will divide these indicators into categories, broadly corresponding to the dimensions of technological regimes we identified in Section 2. This yields the following variables and categories:

i) Nature of the learning process (technological opportunity, cumulativeness)

(1) The intensity of R&D expenditure, estimated by the ratio between the total R&D expenditure of innovators and the total sales of respondents, in 1996[7].

(2) The intensity of R&D employment, estimated by the ratio between the R&D personnel of innovators and the total employment of respondents, in 1996.

(3) The intensity of innovation expenditure, measured by the ratio between the overall innovation expenditure of innovators and the total sales of respondents, in 1996.

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[7] An 'innovator' or 'innovative firm' is defined as a respondent that in 1994-96 has either introduced at least one innovation or engaged in an innovation project (this includes also firms that regularly perform R&D activities, according to the definition by Statistics Netherlands).

(4) The share of innovative turnover, expressed by the percentage of turnover of innovators that is associated with the introduction of products technologically new for the firm on the total turnover of respondents, in 1996.

(5) The share of incremental innovative turnover, measured by the percentage of turnover of innovators that results from technologically improved products on the total turnover of respondents, in 1996.

(6) The share of radical innovative turnover, expressed by the percentage of turnover of innovators from products that are new for the market on the total turnover of respondents, in 1996.

(7) The percentage of innovators on respondents, in 1994-94.

(8) The percentage of product innovators, measured by the percentage of respondents that have introduced at least one product innovation, in 1994-1996.

(9) The percentage of process innovators, estimated by the percentage of respondents that have introduced at least one process innovation, in 1994-96.

(10) The percentage of innovators in a sector that carry out permanent R&D activities (taken as an indicator of the degree of persistence of innovative activities specific to the sector).[8]

ii) Sources of technological knowledge

(1) The relevance of different sources of knowledge for innovation activities, expressed by the percentage of innovators that rank as important or very important the following sources: [9]

- in-house and from affiliates (2 items)

[8] In the Innovation survey, firms are asked whether they undertake (i) permanent R&D activities; (ii) occasional R&D activities, or (iii) none.

[9] Following other authors (Arundel, Van de Paal, and Soete 1995, Klevorick et al. 1995), we assume that the percentage of innovators in a sector that rate as important or very important a source of innovation provides an indicator of the relevance of such a source for innovation in the sector.

- other firms: customers, suppliers, competitors (3 items)
- consultants
- outside the industrial system: universities, 'bridging' institutions such as, TNO[10] and other research centres, innovation centres (3 items)
- publicly available knowledge: conferences and journals, patent disclosures, computer based information networks, and fairs and exhibitions (3 items)

(2) The percentage distribution of innovation expenditure across the following categories:

- in-house activities: R&D, marketing, industrial design, training of personnel (4 items)
- acquired knowledge from other firms: extramural R&D expenditure (broken down by several categories of partners) and the acquisition of licences (2 items)
- capital-embodied (in the form of investment for the acquisition of machinery) (1 item).

(3) The percentage of innovators with formal collaborations, broken down by category of partners:

- within the industrial system (affiliates, customers, suppliers, competitors).
- outside the industrial system (universities, research centres, etc.)

(4) The origin of product innovations, as indicated by the percentage distribution of product innovations resulting from the following three sources:

- exclusively within the firm,
- developed in collaboration,
- exclusively developed by outsiders.

(5) A similar variable as defined under (4) for process innovations.

iii) Factors inducing innovation

(1) The relative importance of product and process innovation, expressed by the ratio between the number of product innovators and the number of process innovators (the assumption is that product and process innovations are driven by separate motives).

(2) The percentage of innovators that ranked the following objectives of innovation as important or very important:

- technology-driven (exploitation of new technological opportunities for the development of new or improved products);
- market-oriented (opening up new markets or increasing market shares)
- cost-cutting motives (of labour, materials, and energy)
- improving flexibility
- responding to external factors (government requirements and environmental concerns).

4. Empirical findings

The empirical results are presented by means of a table for each of the categories of variables identified above. This table contains two parts: a part with descriptive statistics (means and standard errors over sectors within each of the five technological regimes), and a part that documents the results of the statistical tests. In the latter part, we only document the results of tests that were significant at the 10% level or better. Variables for which no significant results were obtained were omitted from the tables. Each table shows the sign of the difference of means of the relevant variables between each combination of regimes (listed in the column header). The corresponding *p*-value is reported in parentheses.

[10] TNO is a Dutch semi-public research institute.

4.1. Nature of the learning process (technological opportunity, cumulativeness)

From the descriptive statistics in the top part of Table 1, it can be concluded that technological opportunities (variables 1-9) are generally highest in the science based, fundamental processes and complex systems regimes. The science based regime ranks highest in 4 out of 9 indicators, the fundamental processes and complex systems regimes each rank highest twice. The continuous processing regime ranks lowest for all except one (% process innovators) of the indicators under this heading.

Table 1 – Nature of the learning process

The bottom part of Table 1 gives an indication of the statistical significance of these differences. Empty cells in this table point to insignificant differences in the mean across sectors between the regimes. There are three noteworthy general impressions from the table. First, the science-based regime yields relatively many significant differences compared to other regimes, and in these cases, the science-based regime always has higher values for the technological opportunity indicators. Second, the fundamental processes and complex systems regimes do not yield a single significant test, pointing out that these regimes score very similar on this set of indicators. Finally, the continuous processes regime also usually yields significant results, but in this case the regime is always characterized by low scores compared to the other regimes.

Summarizing, with regard to the indicators on technological opportunity, the finding is that this is especially high in the science-based sector and especially low in the continuous processes regime. Of the other three regimes, the fundamental processes and complex systems regime cannot really be distinguished from each other, but ('jointly') score somewhat higher than the product-engineering regime.

Zooming in more on the specific indicators of technological opportunity, two results are especially noteworthy. First, while the science based sector generally shows high technological opportunities, it does less so for the indicators with regard to the % innovators of the total population. Thus, apparently, while technological opportunities are generally high in this sector, it seems possible to play a niche strategy without innovation. Second, the turnover % of improved products indicator is low in the science-based sector. This indicates that in this sector, true product innovation is much more important than mere product differentiation.

We have only one indicator of cumulativeness (% of innovators with a permanent R&D department). For this indicator, the fundamental processes regime has the highest value, and this is indeed significantly different from all the other regimes. The continuous processes regime has the lowest value and is also usually significantly different from the other regimes. This is an interesting contrast with the indicators on technological opportunity discussed above. While for the regime with lowest technological opportunities we also find low cumulativeness, high technological opportunities (in the science based regime) do not imply high cumulativeness. Rather, cumulativeness is high in regimes where technological opportunities have intermediate values (complex systems, fundamental processes).

4.2. Sources of technological knowledge

We first consider the relevance of a number of different sources of information (Table 2). With regard to sources within the firm (in-house or affiliates), the differences in relevance attached to these sources do not differ greatly between the five regimes. In-house sources are relatively unimportant for the continuous processes regime (ranking lowest and significantly lower than all other regimes). With regard to knowledge sourced from affiliates, only the fundamental processes and product engineering regimes differ significantly.

Table 2 – Relevance of sources of information

Information sources from other firms do not show very marked differences either. For customers, the continuous processes regime scores relatively low, while the other regimes cannot be distinguished on this variable. For suppliers as a source of information, the continuous processes regime and the complex systems regime score high, although these regimes are only different in a statistically significant way from the product-engineering regime, which is at the bottom of the ranking. Finally, with regard to information obtained from competitors, the fundamental processes regime is at the top of the list, and significantly different from the two regimes at the bottom (product engineering and continuous processes).

The use of information of consultants never differs significantly between regimes, and neither do two of the three items under 'outside the industrial system' (research institutes and innovation centres). For information from universities, the fundamental processes and science-based regimes (respectively) lead the ranking. The differences between these regimes on the one hand, and the product engineering and continuous processes regimes (which score low values) are significant.

Of the public information sources, patents show a significant difference only in combinations where the continuous processes regime is present, indicating the low use of firms in this regime of patent information. For journals and conferences, the product-engineering regime and the continuous processes regime both score low and sometimes significant relative to the other regimes.

Summarizing the findings on information sources, we find that especially the continuous processes and fundamental processes regimes are characterized by profiles that are different from the other regimes. The continuous processes regime depends greatly on information from suppliers, but not on in-house sources or customers. The fundamental processes regime gets relatively much information from universities and from competitors.

Table 3 – Distribution of total innovation expenditure

Turning now to the distribution of innovative expenditures (Table 3), we find more significant differences between the regimes. We first consider expenditures related to internal activities of the firm. In line with the previous results in Table 1, we find that especially the science-based regime relies heavily on in-house R&D, whereas this is a relatively minor source of innovative expenditures for the continuous processes regime. Marketing, on the other hand, is a relatively important source of expenditure in the continuous processes regime. With regard to training, the complex systems regime stands out with a very high share, but this regime is also characterized by a very high standard deviation, and hence it does not appear significant in any test in Table 3. With regard to this indicator, the product-engineering regime (second rank) is significantly different from some of the regimes with lower shares. Of the latter, the science-based regime is the most notable one. Industrial design shows only a significant difference between the top ranking regime (product engineering) and the lowest ranking regime (continuous processes).

Turning to outsourced R&D, it is found that for the total share of this item in innovation expenditures, only the difference between product engineering (high) and continuous processes (low) is significant. For the distribution of outsourced R&D over various categories, however, we find more significant differences. Notably, the continuous processes regime ranks with a high share of R&D sourced from TNO (the semi-public research institute) and foreign affiliates. For these two categories, the continuous processes regime is significantly different from a number of other regimes. The product-engineering regime sources relatively much R&D from domestic non-affiliated firms, but little from foreign affiliates. The fundamental processes regime, finally, sources relatively little from domestic non-affiliated firms, but relatively much from universities. It is notable that the science based regime, although it ranks second with regard to the share of universities in outsourced R&D, it is not significantly different from the other regimes in this respect.

The share of expenditures related to licenses cannot be distinguished significantly between the regimes. The share of machinery in innovative expenditures is significantly higher in the continuous processes regime than in other regimes.

Summarizing the results for the distribution of total innovative expenditures, it can be said that the science based regime and the continuous processes regime are the ones that are relatively ‘special’ with regard to the share of various internal sources. The continuous processes regime, the fundamental processes regime and the product-engineering regime all have rather marked patterns with regard to the distribution of outsourced R&D over various categories.

The next category of variables refers to collaboration in the innovation process. Only few categories of collaborations significantly discriminate across regime (Table 4). Statistically significant differences are observed only for partnerships along the vertical chain of production. In particular, collaborations with suppliers are typical of the complex systems regime. Collaborations with customers prevail in the science-based and fundamental processes regimes, and are relatively infrequent in the product engineering and continuous processes regimes.

Table 4 - Percentage of innovators with collaboration with different kinds of partners

With regard to the origin of innovations (exclusively by the firm, in collaboration or exclusively by others), we see more significant differences for product innovations than for process innovations. In the latter case, the only significant difference is between the continuous processes regime and the fundamental processes regime. The continuous processes regime scores low on innovations made exclusively by the firm, but high on innovations made exclusively by others. For product innovations, the product-engineering regime has a relatively low share of innovations developed exclusively by others. The complex systems regime shows (significantly) a relatively high share of innovations developed by means of collaborations. Finally, the science based and fundamental processes regimes show a high share of innovations developed exclusively by the firm itself, while the continuous processes and complex systems regimes score low on this indicator.

Table 5 - The origin of innovations

4.3. Factors inducing innovations

With regard to the variables that deal with the factors inducing innovations (Table 6), we first look at the ratio between product and process innovations. The product engineering regime scores highest on this variable, the continuous processes regime lowest. More specifically, the first row of Table 6 shows that the continuous processes regime has significantly lower amount of product innovations relative to process innovations compared to all other regimes. The product-engineering regime is also significantly lower than the fundamental processes regime (ranked fourth). However, the top-3 sectors with respect to this variable are not significantly different from each other.

Table 6: Factors inducing innovations

Turning to the objectives of innovation, we first discuss the objectives labelled as 'technology driven'. Of the three different objectives under this heading, the ranking is relatively stable. The complex systems and fundamental processes regimes always rank first and second (respectively), the continuous processes and product engineering regimes generally rank lowest. However, as Table 6 shows, not all these differences are significant. In fact, the differences between regimes for the objective 'extending the product range' are never significant (the scores on this variable thus effectively being equal across regimes). For the objective 'new products', what comes out clearly is that the continuous processes and product engineering regimes score significantly lower than the other three regimes. The latter cannot significantly be distinguished from each other, however. Similarly, for the objective 'product quality', the two regimes with highest importance attached to this objective, i.e., complex systems and fundamental processes can clearly be distinguished from the other three regimes, while the latter are not significantly different from each other.

Demand driven innovation (new markets an market shares) is a variable that is generally not so different between regimes. The fundamental processes regime attaches greatest importance to this objective. The only significant differences between regimes for this variable are found between this regime and the two regimes at the bottom of the ranking, i.e., product engineering and continuous processes. Production flexibility is especially important in complex systems and continuous processes (two highest ranks). These two regimes are significantly different from the other three regimes.

Of the motives related to cost savings, energy costs produce the least amount of significant differences between regimes. For this variable, only the difference between the top (continuous processes) and the bottom (science based) of the list is significant. For material costs, the fundamental processes regime leads the ranking, and this regime is significantly different from all other regimes. No other differences between regimes are found for this objective. Finally, for labour costs, we observe significant differences between the two extremes of the ranking: product engineering and complex systems (attaching most significance to saving on labour) versus science based and fundamental processes (attaching least importance to this).

Fundamental processes is the regime that is most influenced by the external factors ‘environment’ and ‘regulations’. This regime ranks first on both objectives, and is significantly different from most of the regimes at the bottom of the list (notably continuous processes and product engineering).

Summarizing, it is found that especially in the fundamental processes regime, innovation is driven by a wide range of objectives: product quality, markets, to reduce material and labour costs, and to satisfy government requirements and to reduce environmental damages. The other regimes are much more ‘singularly driven’.

4.4. Summary

Some distinctive properties in the profile of technological regimes can be identified from the previous analysis. This profile is described in Table 7 summarising the characteristics of regimes, for which statistically significant differences were observed.

Table 7 The characteristics of technological regimes

In the science-based regime opportunities for innovation are distinctively high, although non-innovative niches appear also possible. These opportunities are *technologically rich*; they reside in new technologies that generate applications for 'true' product innovations (in contrast with factor-prices considerations and strategies of product differentiation). The system of sources of opportunities is centred on the firm, which invests heavily on in-house R&D in combination with the acquisition of knowledge from academic research and collaborative relationships with customers. Specifically, the classification of regimes used in this paper reveal the following properties. It is worth noting that innovation in science-based sectors is not generally associated with an 'entrepreneurial' (or Schumpeter Mark I) regime.

In the fundamental processes regime, a relatively lower level of technological opportunity is associated with highly persistent R&D activities leading to strong cumulativeness of innovative processes. The system of innovation is still 'centred' on the firm, which collaborates with customers but remains the main origin of innovation. However, such a system appears more 'open' to external sources than the science-based regime. Competitors as well as universities are important sources of information. In addition, while from competitors the acquisition of knowledge is only indirect and informal, from universities it involves the outsourcing of R&D. The wide variety of objectives inducing innovation is another distinctive trait of this regime. New technologies are applied for more incremental innovations in product quality. Demand-driven and (materials) costs-saving objectives play a role in the innovation process. External factors related to environmental concerns and government regulations have also a distinctive influence on the innovation process.

The complex system regime is characterised by medium levels of technological opportunity and cumulativeness. Technological opportunities, which rarely lead to 'true' product innovations, are mainly exploited in collaboration by the firm. Suppliers play a distinctive role in the innovation system, being an important source of information and partnership. Innovation strategies combine the application of technologies to increase product quality, with improvements in production processes flexibility and (labour) costs-saving objectives.

The product-engineering regime is characterised by innovative processes which, although relying on medium levels of technological opportunity, generate 'true' product innovations. The new products, developed either by the firm itself or in collaboration, are mainly the outcome of innovative activities associated with industrial design and personnel skills. External sources of opportunities for innovation reside mainly in the outsourcing of R&D, which however remains highly localised in domestic firms. Among these sources, competitors, universities and publicly available knowledge (like journals and conferences) are, compared with other regimes, not important. Unexpectedly, collaborations with customers are relatively infrequent. Innovation strategies appear more respondent to (labour) factor-prices than to the application of new technologies and to the market opportunities.

In the continuous processes regime, technological opportunities are low and not persistent, generating typically process innovations. The distinctive feature of this regime is of a system of innovation almost entirely embodied in the acquisition of machinery, combined with the knowledge contribution from suppliers; however, unlike the complex system regime, the role of suppliers does not extend to stable partnerships. Marketing is the only activity that within the firm appears to contribute to the innovation process; within outsourced R&D foreign affiliated and the TNO (semi-public research institute) play a distinct role. Innovation strategies focus on (energy) costs-saving and the improvement of production processes flexibility; the latter revealing a certain complexity of the production process.

5. Conclusions

In this paper, we tested whether the sectoral patterns of innovation in Dutch manufacturing can be aptly described by using a new model of technological regimes. The model groups industrial sectors in five regimes: science-based regime; fundamental processes regime; complex systems regime; product-engineering regime and continuous processes regime. In order to test this taxonomy data from the second Dutch Innovation Survey were used. The characteristics of innovation processes in each regime were characterised in a number of dimensions, falling into three broad categories: first, the nature of the learning processes; second, the sources of technological knowledge; and third, the factors inducing innovation.

The results showed that significant differences across technological regimes emerge in the properties of innovative processes for Dutch manufacturing firms. These give support to a more disaggregate classification than that between the ‘Schumpeter Mark I’ and ‘Schumpeter Mark II’ patterns of innovation applied by e.g. Malerba and Orsenigo. For example, it accounts for different combinations of opportunity conditions and cumulativeness, as observed between the science-based regime and the fundamental processes regime (broadly corresponding to the ‘Schumpeter Mark II’ type). In addition, it emphasises the distinctive role of partnerships (with suppliers) aimed at the development of collaborative innovations in the complex systems regime (approximately corresponding to a ‘Schumpeter Mark II’ class). In the science-based regime and the fundamental processes regime, collaborations with customers are important, but it is the firm to develop the innovation.

Finally, among those industries in which R&D expenditure does not play a major role (mostly in the ‘Schumpeter Mark I’ group) a distinction emerges between the product-engineering regime and the continuous processes regimes. In the former, industrial design enable firms to introduce fairly innovative products into the market; in the latter, low levels of opportunities are associated with a capital-embodied system of innovation.

We conclude that the empirical analysis of innovation patterns in Dutch manufacturing industries confirms the import of the concept of technological regimes for developing a theory of sectoral systems of innovation. As the analysis showed, technological regimes help to ‘interrogate’ large databases, which address variegated aspects of the innovation process, and provide a useful framework to find regularities for higher levels of aggregation than the standard industrial classification.

Table 1. Nature of the learning process (technological opportunity, cumulativeness)
A. Descriptive statistics

	Science based		Fundamental processes		Complex systems		Product engineering		Continuous processes	
1. R&D exp. intensity	**4.3**	(4.1)	1.7	(1.4)	1.0	(0.9)	1.6	(1.8)	0.4	(0.3)
2. R&D per. intensity	**8.3**	(7.5)	5.8	(3.5)	3.0	(2.4)	3.3	(2.9)	1.1	(0.5)
3. Inn. expenditure intensity	6.6	(5.0)	3.8	(4.1)	**24.5**	(38.2)	3.2	(2.5)	2.3	(1.6)
4. Turnover % new prods	**15.1**	(11.0)	5.8	(3.3)	6.7	(4.6)	8.5	(3.8)	4.5	(2.3)
5. Turnover % improved products	19.0	(8.9)	24.2	(12.9)	**25.9**	(23.8)	19.8	(9.1)	12.1	(7.2)
6. Turnover % new for the market	**8.1**	(6.0)	8.0	(8.0)	4.5	(1.1)	7.1	(4.4)	2.8	(1.9)
7. Innovators % of population	73.0	(12.3)	**82.0**	(12.4)	74.9	(15.2)	64.5	(11.8)	58.9	(16.6)
8. Product innovators % of population	65.8	(9.1)	**77.0**	(16.6)	66.9	(20.9)	59.1	(14.5)	45.2	(16.2)
9. Process innovators % of population	47.6	(15.2)	**62.0**	(7.0)	51.0	(16.3)	39.5	(11.7)	48.1	(16.9)
10. Permanent RD (% of innovators)	57.2	(9.6)	**77.5**	(14.0)	60.1	(12.8)	51.4	(18.8)	41.5	(16.0)

B. Tests for significance of differences between regimes

	SB-FP	SB-CS	SB-PE	SB-CP	FP-CS	FP-PE	FP-CP	CS-PE	CS-CP	PE-CP
1. R&D exp. intensity	+ (0.086)	+ (0.035)	+ (0.070)	+ (0.014)			+ (0.053)			+ (0.011)
2. R&D per. intensity		+ (0.079)	+ (0.069)	+ (0.014)		+ (0.074)	+ (0.012)			+ (0.003)
3. Inn. expenditure intensity			+ (0.069)	+ (0.024)						
4. Turn % new prods	+ (0.049)		+ (0.097)	+ (0.014)						+ (0.000)
5. Turn % improved prods				+ (0.027)			+ (0.050)			+ (0.004)
6. Turn % new for the market		+ (0.105)		+ (0.021)				- (0.051)		+ (0.000)
7. Innovators % of pop.			+ (0.079)	+ (0.024)		+ (0.003)	+ (0.002)			
8. Prod. innov. % of pop.				+ (0.001)		+ (0.012)	+ (0.000)		+ (0.046)	+ (0.006)
9. Proc. innov. % of pop.	- (0.035)					+ (0.000)	+ (0.005)			- (0.066)
10. R&D persistence	- (0.003)			+ (0.002)	+ (0.104)	+ (0.003)	+ (0.000)		+ (0.067)	+ (0.071)

Notes: In Part A, numbers without brackets are means, numbers within brackets are standard deviations. Numbers in bold are the maximum value among the five regimes. In Part B, the +/- signs correspond to significant differences between the regimes (with the sign pointing to the sign of the difference), the numbers between brackets in Part B are *p*-values (the cut-off point for reporting is the 10% significance level).

Table 2 Relevance of sources of information
A. Descriptive statistics

	Science based		Fundamental processes		Complex Systems		Product engineering		Continuous processes	
Within the firm										
In-house sources	87.9	(10.4)	**89.9**	(5.7)	89.3	(10.1)	84.7	(9.3)	76.3	(10.1)
Affiliates [a]	58.2	(38.0)	74.8	(19.1)	**75.3**	(38.1)	53.5	(24.7)	59.3	(37.6)
Other firms										
Clients or customers	57.8	(18.5)	54.0	(8.0)	**58.3**	(4.6)	53.3	(13.8)	39.6	(14.2)
Suppliers	36.7	(17.4)	34.0	(25.1)	**49.5**	(12.4)	32.2	(10.2)	39.1	(10.5)
Competitors	35.7	(19.1)	**41.8**	(11.2)	40.6	(19.9)	29.4	(10.6)	28.0	(11.9)
Consultants	7.9	(10.5)	15.0	(9.7)	**20.4**	(12.4)	9.8	(5.0)	12.5	(7.1)
Outside industrial system										
Research instit. (e.g. TNO)	13.0	(9.5)	**18.4**	(11.3)	15.9	(8.5)	12.4	(7.6)	14.6	(10.6)
Universities	17.8	(11.6)	**18.8**	(12.4)	9.0	(10.2)	10.0	(7.2)	7.3	(5.7)
Innovation centres	6.7	(6.6)	5.6	(9.3)	9.3	(8.3)	**10.4**	(7.4)	7.4	(6.1)
Public sources										
Patent disclosure	9.1	(9.3)	**16.6**	(13.0)	10.8	(4.3)	8.3	(6.5)	4.2	(4.3)
Computer based inform.	11.2	(12.9)	**11.6**	(11.1)	4.6	(7.9)	5.0	(4.3)	6.8	(6.3)
Conferences, journal	39.7	(13.7)	**45.1**	(14.2)	34.7	(7.2)	30.8	(11.0)	32.0	(13.8)
Fairs and exhibitions	40.1	(18.2)	29.1	(8.5)	**42.4**	(7.1)	39.9	(16.2)	37.7	(13.4)

B. Tests for significance of differences between regimes

	SB-FP	SB-CS	SB-PE	SB-CP	FP-CS	FP-PE	FP-CP	CS-PE	CS-CP	PE-CP
Sources within the firm										
In-house				+ (0.006)			+ (0.002)		+ (0.047)	+ (0.008)
Affiliates[b]						+ (0.049)				
Other firms										
Customers				+ (0.005)			+ (0.018)		+ (0.036)	+ (0.003)
Suppliers								+ (0.014)		- (0.036)
Competitors						+ (0.014)	+ (0.011)			
Universities[a]			+ (0.076)	+ (0.020)			+ (0.050)			
Public sources[c]										
Patents							+ (0.046)		+ (0.021)	+(0.018)
Journal, conferences			+ (0.064)			+ (0.011)	+ (0.039)			
Fairs and exhibitions					- (0.046)					

Notes: See Table 1. (b) The source 'affiliates' is not relevant for independent firms. It covers just over 38 percent of the 6052 innovative firms, which operate within an industrial group.

Table 3 Distribution of total innovative expenditures
A. Descriptive statistics

	Science based		Fundamental processes		Complex Systems		Product engineering		Continuous processes	
Internal sources										
Intramural R&D	**60.8**	(17.6)	51.3	(21.0)	33.4	(28.5)	45.3	(17.3)	26.4	(18.2)
Marketing	4.9	(7.6)	2.1	(1.4)	1.2	(1.3)	2.5	(1.3)	**8.4**	(13.0)
Training	1.5	(1.0)	1.8	(1.8)	**34.0**	(53.4)	3.2	(1.6)	2.7	(1.5)
Industrial design	4.5	(3.8)	4.9	(5.7)	5.5	(4.9)	**6.5**	(5.0)	3.5	(4.1)
Acquired knowledge, of which										
Extramural R&D, of which	6.8	(5.4)	6.2	(3.4)	**10.4**	(12.7)	7.4	(4.8)	5.0	(3.7)
Domestic affiliates	5.3	(15.8)	**19.9**	(27.7)	*	*	4.2	(5.0)	7.6	(19.1)
Other domestic firms	41.7	(19.5)	12.0	(16.3)	*	*	**55.4**	(22.1)	33.4	(23.3)
TNO	3.3	(3.6)	6.5	(3.5)	*	*	5.6	(5.5)	**10.0**	(7.3)
Universities	3.9	(6.2)	**13.3**	(8.9)	*	*	3.0	(4.9)	2.9	(4.3)
Other research institutes	1.3	(1.1)	3.6	(3.7)	*	*	4.6	(8.6)	4.7	(4.3)
Foreign affiliates	6.8	(3.2)	18.1	(22.5)	*	*	9.7	(15.6)	**23.1**	(25.3)
Other foreign third [b]	37.7	(18.6)	26.7	(18.7)	*	*	17.5	(19.2)	18.2	(21.3)
Licences	1.0	(0.7)	1.2	(1.0)	0.9	(0.9)	**1.9**	(2.1)	1.4	(3.8)
Machinery	20.4	(15.2)	32.6	(25.7)	14.6	(12.8)	33.3	(18.9)	**52.7**	(25.6)

B. Tests for significance of differences between regimes

	SB-FP	SB-CS	SB-PE	SB-CP	FP-CS	FP-PE	FP-CP	CS-PE	CS-CP	PE-CP
Internal sources										
In-house R&D		+ (0.062)	+ (0.029)	+ (0.000)			+ (0.005)			+ (0.001)
Marketing							- (0.036)			- (0.045)
Training			- (0.006)	- (0.040)		- (0.065)				
Industrial design										+ (0.046)
Extramural R&D of which										+ (0.073)
Other firms	+ (0.005)		- (0.109)		- (0.040)	- (0.000)	- (0.032)			+ (0.003)
TNO	- (0.092)			- (0.002)			- (0.100)			- (0.032)
Research institutes				- (0.002)						
Universities	- (0.021)				+ (0.011)	+ (0.021)	+ (0.021)			
Foreign affiliates		+ (0.006)		- (0.007)	+ (0.083)				- (0.000)	- (0.045)
Other foreign			+ (0.010)	+ (0.018)				+ (0.090)		
Machinery			- (0.072)	- (0.000)			- (0.082)		- (0.020)	- (0.008)

Notes: See Table 1. * The distribution of extramural R&D is relevant only for the firms responding to the R&D survey, which represent the 16 per cent of the CIS sample. This number falls below the confidentiality threshold of 15 firms in the case of the complex system regime.

Table 4 Percentage of innovators with collaboration with different kinds of partners
A. Descriptive statistics

Partners	Science based		Fundamental processes		Complex Systems		Product engineering		Continuous processes	
Affiliates [ac]	23.6	(20.0)	28.6	(18.3)	**29.1**	(5.4)	23.0	(21.5)	27.0	(23.6)
Customers	22.1	(12.6)	**26.3**	(12.9)	18.8	(10.1)	14.2	(7.4)	13.9	(11.4)
Suppliers	15.7	(13.0)	12.8	(7.1)	**31.7**	(13.3)	11.1	(5.7)	17.4	(12.9)
Competitors	5.3	(7.7)	**8.8**	(7.7)	8.7	(2.7)	6.0	(5.4)	8.7	(8.2)
Consultancies	8.0	(10.5)	**11.4**	(11.1)	8.5	(9.3)	5.3	(4.7)	6.7	(5.4)
Research institutes	9.7	(8.7)	11.8	(8.3)	**13.1**	(11.7)	7.8	(5.3)	11.5	(14.3)
Universities	9.6	(9.7)	9.4	(4.1)	**11.3**	(6.2)	7.5	(5.5)	7.7	(9.2)

B. Tests for significance of differences between regimes

	SB-FP	SB-CS	SB-PE	SB-CP	FP-CS	FP-PE	FP-CP	CS-PE	CS-CP	PE-CP
Customers			+ (0.039)	+ (0.080)		+ (0.049)	+ (0.022)			
Suppliers		- (0.089)			- (0.016)				+ (0.087)	- (0.048)

Notes: See Table 1.

Table 5 The origin of innovations (% of all innovations)
A. Descriptive statistics

	Science based		Fundamental processes		Complex Systems		Product engineering		Continuous processes	
Product innovations:										
exclusively others	15.0	(9.6)	11.4	(10.3)	**18.9**	(15.5)	6.1	(5.8)	13.0	(10.4)
collaboration	19.9	(10.6)	20.2	(11.4)	**35.9**	(4.8)	26.7	(11.8)	25.0	(12.7)
exclusively the firm itself	**73.1**	(12.7)	70.8	(14.3)	52.7	(11.7)	66.3	(16.8)	54.9	(18.2)
Process innovations										
exclusively others	31.1	(19.1)	24.1	(14.6)	29.8	(19.7)	31.4	(15.1)	**35.1**	(15.2)
collaboration	36.6	(12.2)	32.7	(20.3)	37.0	(7.4)	33.5	(13.0)	**39.9**	(13.6)
exclusively the firm itself	41.9	(13.1)	**49.1**	(15.8)	36.5	(23.4)	41.5	(15.3)	33.7	(17.5)

B. Tests for significance of differences between regimes

Indicators	SB-FP	SB-CS	SB-PE	SB-CP	FP-CS	FP-PE	FP-CP	CS-PE	CS-CP	PE-CP
Product innovations										
exclusively by others			+ (0.004)							- (0.012)
collaboration		- (0.031)			- (0.016)					
exclusively by the firm		+ (0.031)		+ (0.008)	+ (0.091)		+ (0.045)			+ (0.043)
Process innovations										
exclusively by others							- (0.104)			
collaboration										
exclusively by the firm							+ (0.047)			

Notes: See Table 1.

Table 6 Factors inducing innovations

A. Descriptive statistics

	Science based		Fundamental processes		Complex Systems		Product engineering		Continuous processes	
1. Ratio of product and process innovators	1.45	(0.30)	1.24	(0.21)	1.37	(0.41)	**1.56**	(0.43)	0.99	(0.27)
2. (Very) important objectives:										
Technology-driven										
New products	58.6	(19.9)	63.0	(10.2)	**67.9**	(5.8)	48.5	(18.3)	38.9	(11.2)
Product quality	76.9	(15.1)	87.6	(7.7)	**93.5**	(6.7)	77.4	(7.7)	81.0	(8.6)
Product range	70.4	(16.6)	73.0	(9.2)	**77.8**	(19.1)	65.5	(14.5)	65.7	(11.5)
New markets and market shares	71.7	(14.0)	**78.2**	(9.7)	61.6	(28.2)	66.0	(12.4)	66.5	(12.3)
Production process flexibility	45.5	(20.6)	54.6	(6.9)	**72.0**	(5.0)	55.5	(10.2)	62.1	(13.2)
Reducing costs, of which										
Labour costs	45.6	(15.1)	43.0	(12.1)	50.7	(3.5)	**54.5**	(11.9)	54.4	(11.8)
Materials costs	34.8	(17.0)	**63.2**	(14.3)	45.8	(9.6)	35.3	(10.8)	39.1	(16.5)
Energy costs	25.5	(13.8)	38.4	(20.0)	29.9	(11.0)	31.0	(16.4)	**38.9**	(16.7)
External factors, of which										
Government requirements	50.1	(17.5)	**60.0**	(7.6)	57.2	(23.0)	45.2	(17.3)	43.2	(14.8)
Environmental damage	42.0	(12.6)	**70.4**	(10.2)	56.5	(13.8)	43.0	(16.6)	45.6	(17.3)

B. Tests for significance of differences between regimes

	SB-FP	SB-CS	SB-PE	SB-CP	FP-CS	FP-PE	FP-CP	CS-PE	CS-CP	PE-CP
1. Ratio Product / Process innovations				+ (0.000)		- (0.068)	+ (0.041)		+ (0.044)	+(0.000)
2. (Very) important objectives:										
Technology-driven[a]										
New products				+ (0.001)		+ (0.059)	+ (0.000)	+ (0.088)	+ (0.000)	+ (0.052)
Product quality	- (0.075)	- (0.098)				+ (0.006)	+ (0.029)	+ (0.003)	+ (0.024)	
New markets and market shares						+ (0.026)	+ (0.029)			
Production process flexibility		- (0.003)		- (0.037)	- (0.004)		- (0.065)	+ (0.013)	+ (0.043)	- (0.080)
Reducing costs, of which										
Labour costs			- (0.088)	- (0.084)		- (0.037)	- (0.065)			
Materials costs	- (0.003)				+ (0.095)	+ (0.000)	+ (0.002)			
Energy costs				- (0.035)						
External factors, of which										
Regulations						+ (0.039)	+ (0.001)			
Environment	- (0.000)					+ (0.000)	+ (0.001)			

Notes: See Table 1.

Table 7 The characteristics of technological regimes

	Science based	Fundamental processes	Complex systems	Product engineering	Continuous processes
Nature of the learning process					
Opportunity	High	Medium - High	Medium - High	Medium	Low
Cumulativeness	Medium	High	Medium	Medium	Low
Sources of technological knowledge					
Sources of information	High relevance of: - universities	High relevance of: - competitors - universities	High relevance of: - suppliers	Low relevance of: - competitors - universities - journals and conferences	Low relevance of: - in-house - customers - competitors - universities - patents - journals and conferences High relevance of: - suppliers
Shares of innovation expenditures	High share of: - in-house R&D Low share of: - training Within outsourced R&D, high importance of: - foreign third	Within outsourced R&D, high importance of: - universities - foreign affiliates Within outsourced R&D, low importance of: - domestic firms	Within outsourced R&D, high importance of: - foreign third Within outsourced R&D, low importance of: - foreign affiliates	High share of: - training - outsourced R&D - design Within outsourced R&D, high importance of: - domestic firms Within outsourced R&D, low importance of: - foreign affiliates - foreign third	High share of: - marketing - machinery Low share of: - in-house R&D - outsourced R&D - design Within outsourced R&D, high importance of: - TNO - foreign affiliates
Collaboration	High relevance of: - customers	High relevance of: - customers	High relevance of: - suppliers	Low relevance of: - customers	Low relevance of: - customers
The origin of innovations	Product innovations: - excl. the firm itself	Product innovations: - excl. the firm itself	Product innovations: - not excl. by the firm - collaboration	Product innovations: - not excl. by others	Process innovations: - not excl. by the firm - excl. by others Product innovations: - not excl. by the firm

Factors inducing innovations					
Ratio product - process innovation				High	Low
Innovation objectives	Low importance: - energy saving	High importance: - product quality - new markets & market share - materials saving - regulations - environment	High importance: - product quality - process flexibility - labour saving	High importance: - labour saving Low importance: - new products - new markets & market share	High importance: - process flexibility - energy saving Low importance: - new products - new markets & market share

APPENDIX

Table I. Industries in technological regimes

Science based	Fundamental processes	Complex systems	Product engineering	Continuous processes
Pharmaceuticals Computers Electric motors, generators etc. Electricity distribution and control Insulated wires and cables, accumul. Lighting equipment Electrical equipment n.e.c. Electronic components Telecommunication equipment Photocopy and photographic equip.	Coke and refined petroleum Inorganic basic chemicals Organic chemicals Resins and man made fibres Paints, vanishes, etc. Soap, detergents, perfumes Other chemical products	Motor vehicles Motorcycles and bicycles Other transport equipment (incl. aircraft)	Rubber and plastic products Structural metal products Tanks, reservoirs, central heating, etc. Forging, pressing; powder metallurgy Treating and coating of metals Cutlery, tools and general hardware Other fabricated metal products Machinery for power production and use Lifting and handling equipment Non-domestic cooling-ventilation equip. Other general machinery n.e.c. Agricultural machinery Special purpose machinery Domestic appliances n.e.c Medical and surgical equipment Measuring and control instruments Bodies for motor vehicles Parts and accessories for motor vehicles Shipbuilding and repairing Miscellaneous manufacturing n.e.c.	Food products Beverage Tobacco products Textiles processes Made-up textiles Other textiles Knitted and crocheted fabrics/articles Wearing apparel Leather and leather products Wood and wood products Pulp and paper Paper articles Publishing Printing Glass, glass and ceramic products Bricks, tiles and construction products Other non -metallic mineral products Basic ferrous metals Basic precious and non-ferrous metals Casting of metals Furniture Recycling
Innovators = 308 % [a] = 70.3	Innovators = 280 % = 84.7	Innovators = 66 % = 73.7	Innovators = 2747 % = 62.9	Innovators = 2651 % = 52.8

Note: (a) The percentages in this row present the number of innovators compared to all firms employing 10 or more workers.

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