How much do innovation strategies differ across firms, industries and countries?*

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Abstract

Our aim is to quantify innovation strategies of firms based on evidence from the CIS data. Using exploratory factor analysis on micro data from CIS3 in 13 countries, we identify four factors that that can be interpreted as research-based, user-driven, extensive and social responsibility innovation strategies. Since it has been put forward that diversity in the way how firms innovate can be explained by differences across sectors and/or countries, we explore to what extent the innovation strategy of a firm is influenced by this context. We use cross-classified mixed-effects model to partition the variation of innovation strategies into components identified by sectors, countries, and idiosyncrasies at the firm level. The analysis shows that sectors and countries matter to a certain extent, but most of the variance (from 80 to 95%) is given by heterogeneity among firms.

Keywords: Heterogeneity, innovation strategy, innovation system, factor analysis, mixed-effects model.

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1. Introduction

Economists have traditionally considered innovation as a one-dimensional phenomenon that can usefully be described by an input-output relation (e.g., Crépon and Duguet, 1998 and other work on the "innovation production function"). Research and Development (R&D) has been used as the main input indicator, and outputs have been proxied by such diverse indicators as productivity, patents, and innovation counts. The Community Innovation Survey (CIS) arose from the dissatisfaction of some economists with this state of affairs (Smith, 2004). They argued that innovation decisions of firms are not only concerned with how much innovation efforts to make, but especially with what kinds of innovation strategies to pursue. This followed on early work by, among others, Freeman and collaborators at SPRU, who argued on the basis of qualitative evidence that firms could employ diverse set of innovation strategies. For example, Freeman (1974) distinguished between six innovation strategies: offensive, defensive, imitative, dependent, traditional and opportunistic.

Our first research aim is to quantify such innovation strategies based on the available European-wide evidence from the CIS data. We use exploratory factor analysis to classify firms' innovation efforts, and to investigate whether the results of such a classification can be linked to the typologies proposed in the literature. The analysis is based on micro data from the third Community Innovation Survey (CIS-3) provided by Eurostat, which asked firms about various aspects of their innovation activity from 1998 to 2000. After omitting observations with incomplete records the survey provides a dataset of 13,035 innovating firms in both industry and market services in thirteen European countries. Our results identify four principal factors that can be interpreted as research-based, user-driven, extensive and social responsibility innovation strategies.

Since it has been put forward that diversity in the way how firms innovate can be explained by differences across sectors and/or countries (Pavitt, 1984; Malerba and Orsenigo, 1995; Lundvall, 1992; Nelson, 1993), the second research question is to what extent the innovation strategy of a firm is influenced by this context. Using cross-classified mixed-effects model, we partition the variation of innovation strategies into components identified by sectors, countries, and idiosyncrasies at the firm level (Goldstein, 2003 and Hox, 2002). The analysis shows that sectors and countries matter to a certain extent, but most of the variance (from 80 to 95%) is given to heterogeneity among firms. Another interpretation is that although the higher levels tested in the analysis do not matter much, there can be another hierarchical structure of the data (hidden to us at this point), that can explain more (such as a different or more detailed industrial classification and regional levels in the spatial dimension).

2. Diverse routes to success in innovation

2.1 Firm-level heterogeneity

Innovation is considered as a key factor determining the competitiveness of firms, not only by policymakers, but also by management theory. Especially the so-called resource-based view of the firm (Wernerfelt, 1984) is a useful framework for analyzing this relationship. The resource-based literature views the important resources that firms use as heterogeneous and non-mobile. The aim of this literature is to explain the competitiveness, or potential for value creation, of firms, often in a comparative (between firms) setting.

Amit and Schoemaker (1993) suggest the term capabilities for describing those resources of the firm that are specific and not easily tradable. These capabilities are the core of a long-run, sustainable ability of the firm to be competitive, and hence of the resource-based theory of the firm. It is the non-mobile, or non-imitable character of these capabilities that makes the competitive advantage that results from it sustainable. Any resource that is easily imitable by other firms will lead to competition, and hence erode value creation.

Because knowledge and human capital are prime examples of capabilities that are not easily transferred between firms, innovation is a very natural topic for a resource-based view of the firm (Teece and Pisano, 1994). The economic literature on innovation, with Nelson and Winter's (1982) 'evolutionary' view as a central topic, closely links up to this idea (Montgomery, 1995). Nelson and Winter also start from the central idea that firm capabilities for innovation are heterogeneous and idiosyncratic. They add elements of a behavioural theory of the firm, going back to Cyert and March (1963), and Simon's idea of bounded rationality (Simon, 1991).

The idea of bounded rationality implies that firms, even when working in a similar general environment such as a sector or country, may adopt widely differing strategies, because they interpret the environment differently, and use different 'models' for reaching decisions on firm strategy. In addition to this, Cyert and March (1963) stress that the firm itself must be seen as a coalition of various interest groups (e.g., top managers, middle management, workers, stockholders), and that the interaction between these adds another element of heterogeneity.

In line with these theoretical foundations (Dosi, 1998 provides an overview) , the current innovation literature in economics and management studies considers a broad range of possible forms, sources and outcomes of innovation processes. Important topics in this literature are, for example, knowledge sources (e.g., Laursen and Salter, 2004), cooperation in innovation (Powell et al, 1996), joint ventures (Mowery, 1989), imitative innovation (Cohen and Levinthal, 1989), location of innovation activities (Von Hippel, 1994), the degree, and extent and effects of innovation (Bower and Christensen, 1995). All these issues can be summarized under the question *how* firms innovate, as opposed to the question *how much resources* they devote to innovation.

Note that mainstream economics – treating the firm as a profit maximizer that has to choose the optimal level of inputs, and, in non-competitive environments, price – is still much occupied with the latter question. This is apparent in, for example, models on so-called patent races (e.g., Reinganum, 1981), which analyze how the firm chooses its level of R&D spending in the light of competitors' behaviour.

2.2 Sectoral and national patterns (sectoral and national innovation systems)

While heterogeneity in firm behaviour and resources is a central idea in the innovation literature, attempts have also been made to reduce heterogeneity into a more limited number of stylized patterns that summarize the main differences between firms. Our empirical analysis below can also be considered as such an attempt.

Traditionally, the starting point for such summaries of heterogeneity has been the notion that the nature of the innovation process also depends on the context within which the process occurs. This suggests that within broad classes of the firm's environment, heterogeneity is smaller than between such classes. This is the starting point for Pavitt (1984), who suggested to analyse differences between sectors, and which has inspired a lively debate in the innovation literature ever since (for surveys see Archibugi, 2001, Peneder, 2003). This idea has more recently has been developed into the concept of sectoral innovation systems (Malerba and Orsenigo, 1995).

Pavitt's (1984) contribution was a categorization of (sectoral) diversity into only four classes. He compared sectors according to sources of technology used in the innovation process, nature of the technology produced, sectors of use of their innovations, and characteristics of innovating firms with regards to their size and principal activity. Using information on these variables for 2,000 significant innovations in British firms over 1945-1979, he identified common technological patterns at the sectoral level, and categorized the various manufacturing industries into four groups: 1) Supplier-dominated, 2) Scale intensive, 3) Specialized suppliers, and 4) Science-based sectors. It should be pointed out, however, that what Pavitt really had in mind when constructing the taxonomy was how the innovation process is organized within firms (and what are the differences in this respect between firms). Nothing can be more revealing than this quote from the original paper: "…technology trajectories are directions of technical development that are cumulative and self-generating, without repeated reference to the economic environment external to the firm." (Pavitt, 1984, p. 355).

However, in the two-step process that Pavitt adopted (aggregation of the firm-level data to the sectoral level certainly, and subsequently reducing this to identify the four sectoral classes), a lot of firm-level diversity may have been lost. The literature following Pavitt has not returned to the question how firm level heterogeneity within the sectors, let alone the sectoral aggregates, related to that between the sectors and the four classes of the taxonomy. Instead, the literature has used the taxonomy as a useful classification tool in empirical work that does away with the strongest effects of heterogeneity. Our proposal in this paper is to get back to the lowest level of heterogeneity, i.e., the firm, and formally address the question how aggregation affects the loss of this heterogeneity.

But sectoral and firm level patterns of innovation are also determined by the local institutional, cultural and other factors, which is well-understood in the literature on national innovation systems (Lundvall, 1992; Nelson, 1993). The idea in this literature is that heterogeneity between firms is somehow limited by national borders, but that there is substantial diversity of national systems of innovation and production. Much the same critique about ignoring heterogeneity within national systems applies to this literature. Moreover, sectoral and national systems of innovation interact. In particular, sectoral patterns of innovation in small, structurally different and most importantly developing countries differ substantially from their general characteristics observed in the rest of the world (Srholec, 2007). It is too often taken for granted in the empirical literature that the taxonomic characteristics of industries are equally relevant across countries (and in time), and the taxonomy is applied in a “one-fits-all” manner in empirical research. The identification problem is not resolved by grouping industries once for all (Peneder, 2003). Since countries differ in their institutions, culture (etc.), also sectoral technology trajectories differ even if the principal activity of firms appears to be the same according to standard industrial classifications.

We conclude that there are not many studies that directly investigate and test the relevance of the sectoral taxonomies, or national systems by quantitative analysis. One of the reasons used to be a lack of disaggregated data on innovation, but the CIS databases, which are now commonly available at the micro level in most countries in Europe and some countries in the rest of the world, seem to fill this gap. Analyses based on such a database constructed in the SIEPI project suggest that there is substantial variety in sectoral innovation process across countries (Castellacci 2004 and 2005). Although this is a step forward in the analysis, first and foremost one needs to take into account the differences at the firm-level, which arguably may be the most important and underlay the sectoral and national patterns.

Although there is extensive evidence on characteristics of the innovation process at the firm-, sector- and country-levels, our understanding of interaction between the various levels of the analysis remain to be rather limited. How much can we explain by differences across firms, industries and countries? How much of the innovation strategy of the firm is determined by the sectoral and national context and how much is given by heterogeneity at the firm level? In order to answer this question, we fist need to identify the variety of innovation strategies that can be observed at the firm-level.

3. Overview of the dataset

The analysis is based on micro data from the third Community Innovation Survey (CIS-3) provided by Eurostat (Eurostat, 2007), which asked firms about various aspects of their innovation activity from 1998 to 2000 (or in some countries from 1999 to 2001).[1] Following the Oslo Manual (OECD, 1997), a harmonized questionnaire and methodology was used to collect the data. Only firms that successfully introduced product or process innovation over the period were included in the analysis. After omitting observations with incomplete records the survey provides a dataset of 13,035 innovating firms in industry and most sectors of market services (10-74 codes according to NACE, rev. 1.1) in thirteen European countries (Belgium, Bulgaria, Czech Republic, Estonia, Germany, Greece, Latvia, Lithuania, Norway, Portugal, Romania, Slovakia and Spain).[2]

Information about the innovators in the survey refers to resources devoted to variety of innovation activities, to effects of innovation, to the main sources of information for innovation, to cooperation agreements on innovation with other firms and organizations, to use of methods to protect innovations and to other important changes in the enterprise. Let us overview variables derived from the survey that are used in the analysis (for more details on definitions and formulation of the questions see OECD, 1997 and Eurostat, 2007).

The variables derived from the question on different innovation activities are dummies with value 1 if the firm indicated to engage in the particular activity as follows: i) Intramural research and experimental development (R&D), ii) Acquisition of extramural R&D, iii) Acquisition machinery and equipment specifically purchased to implement the innovation, iv) Acquisition of other external knowledge (licenses, software and other), v) Internal or external training directly aimed at implementation of the innovation, vi) Internal or external marketing activities directly aimed at the market introduction of the new products, and vii) Design and other preparations for production or deliveries not covered elsewhere. To keep the entire analysis at the firm level, we refrain from using information on innovative expenditures devoted to these activities, because these variables have been micro-aggregated.

Another set of questions asked firms how they benefited from results of the innovative activity. Firms were asked to indicate the degree of the following effects on a four-point scale: i) Increased range of goods or services, ii) Increased market or market share, iii) Improved quality in goods or services, iv) Improved production flexibility, v) Increased production capacity, vi) Reduced labour costs per produced unit, vii) Reduced materials and energy per produced unit, viii) Improved environ-

[1] Some of the variables in the dataset containing sensitive financial information were so-called micro-aggregated by averaging data for three similar firms. Since the only micro-aggregated information used in this paper in on the weights, evidence on innovation strategies in this paper is based on data directly at the firm-level.

[2] Data from Iceland and Hungary must have been excluded from the analysis. Only about one third of innovating firms answered detailed questions on their innovation activity in Iceland. Observations from Hungary were omitted for various reasons; information on the complexity of design as the method of protection was missing, the national dataset contains a very low number of innovating firms and the set of Hungarian firms proved to be a major outlier if included in the analysis.

mental impact or health and safety aspects, and ix) Met regulations or standards. Answers were coded by integers from zero for “not relevant” to four for “high degree of impact”.

As for the main sources of information, firms were asked to indicate on a similar four-point Likert scale importance of the following: i) Within the enterprise, ii) Other enterprises within the enterprise group, iii) Suppliers of equipment, materials, components or software, iv) Clients or customers, v) Competitors and other enterprises from the same industry, vi) Universities or other higher education institutes, vii) Government or private non-profit research institutes, viii) Professional conferences, meetings, journals, and ix) Fairs and exhibitions. However, we do not include the variable on importance of the “other enterprises in the group” in the analysis because the Greek version of the survey did not provide this information on question. Again the answers were coded by integers from zero for “not used” to four for “high importance”.

Somewhat related information comes out from the set of questions on cooperative arrangements on innovation. Innovation cooperation is defined in the survey as active participation in joint R&D and other innovation projects with other organisations. Firms were asked to report whether they had cooperative agreements broken down by a similar division of partners as in the question on sources of information above. Since the role of different types of external organizations in the innovation process is already captured by the previous set of questions (and because including redundant information in factor analysis tend to produce so-called “inflated factors”, which should be avoided), we use only the information on occurrence of at least one cooperation agreement on innovation. From this follows the variable on innovation cooperation is a dummy with value 1 if the firm has any cooperation arrangements (regardless of the partner organization).

A salient aspect of the innovation strategy is how the firm protects outcomes of the innovation activity. Firms were asked to indicate whether they used some of the following methods to protect inventions or innovations developed by the enterprise: i) application for a patent, ii) registration of design patterns, iii) Trademarks, iv) Copyright, v) Secrecy, vi) Complexity of design, and vii) Lead-time advantage on competitors. A dummy variable for each option has value 1 if the firm reported to use the respective method of protection.

Finally, a set of dummies with value 1 for a positive answer have been derived from the question on other important changes in the firm, which include i) Implementation of new or significantly changed corporate strategies, ii) Implementation of advanced management techniques within the enterprise, iii) Implementation of new or significantly changed organizational structures, iv) Changing significantly the firm’s marketing concepts/strategies, and v) Significant changes in the aesthetic appearance, design or other subjective changes of the product.[3]

[3] Some adjustment/clearing of the dataset was necessary before the analysis in the particular order as follows (note that the following refers only to the sub-sample of innovating firms). First, we have replaced missing data by zeros if there was at least one valid answer within the particular set of questions (such as the set of question of effects of innovation, etc.). Although this may seem as a relative heroic assumption, for some countries this has been apparently done already before distributing the dataset, while for others not, so that this procedure was necessary to harmonized the data along these lines.

4. Hierarchical factor analysis

Innovation strategy of a firm is a multidimensional phenomenon. As discussed above different typologies of the innovation process at various levels have been proposed in the literature over the years and a number of measures have been used to pinpoint their most salient features. How can we detect innovation strategies of firms? An obvious possibility is to gather the relevant indicators and attempt to connect the dots by an essentially descriptive analysis, which tends to be the most common approach in the literature. Such approach is feasible if a small number of indicators is taken into account, but suffers from severe limits if somewhat richer evidence becomes investigated, because the number of dots that need to be connected tends to grow exponentially with the increasing number of variables in the analysis. And we need to take into account a large number of factors in order to derive robust evidence on innovation strategies of firms.

Fortunately, there is a well developed method of multivariate analysis - the so-called factor analysis – that can help us to identify the underlying structure of a multidimensional problem in a concise manner. Factor analysis has been widely used in psychology and other social sciences for a long time (Spearman, 1904; Hotelling, 1933), but it has been sparsely and only recently used in research on innovation (Hollenstein, 2003; Fagerberg and Srholec, 2006; Leiponen, Drejer, 2007). It is ideal tool of analysis if data are complex and we are not sure what are the most important dimensions underlying the dataset.

Although it can not be purpose of this paper to provide a general overview of the method and a number of its variations (for a more details see Kline, 1994 or Basilevsky, 1994), we need to explain why we use hierarchical approach to factors analysis. The idea is that firms first choose from different options within the particular aspect of the innovation strategy and then combine these aspects together in the innovation process. In other words, we assume that a firm needs to engage in some type of innovation activity, needs to use some source of information for innovation, etc. and therefore we conceptualize the decision of a firm on the innovation strategy as consisting from hierarchically-ordered layers. In order to dress up comfortably for bad weather, one needs to put on at least one layer of each kind of cloth. Just like it is not advisable to go out into cold with five different hats, but no pants on, a firm needs to combine different aspects of the innovation strategy, which entail a decision on variety of options within each of them.

From this follows that it is logical to model the decision of a firm on the innovation strategy as two-stage process. First we conduct the factor analysis separately

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Second, only firms with non missing information on all of the variables used in the analysis (after imputation of the missing data by the preceding procedure) were included in the analysis (528 firms were deleted). Third, firms with only zeros in the set of questions on the various innovation activities (i.e. those that did not have any innovation activity in 2000) were excluded from the analysis (about 1,200 firms); after deleting these firms the same has been done for the effects of innovation (another 70 firms deleted); and the same for sources of information (another 310 firms deleted); but this procedure has not been applied on the methods of protection and on the other changes in the enterprise (since these may have not occurred at all in the enterprise). It was necessary to exclude these observations in order to prevent zeros in these questions to bias the estimates, because these zeros are likely to reflect unwillingness of firms to provide the information rather than reporting “no occurrence”, “not relevant” or “not used” in the respective questions.

on each set of the CIS questions, and then in the second step we input principal factors obtained from these lower-order estimates into the higher-order factor analysis, which reveals the different innovation strategies of firms. After all, also the design of the CIS questionnaire is implicitly hierarchical, because firms are asked on the different groups of questions together, so that it is natural to understand them as separate statements about their innovation strategy. Using factor analysis on all of the variables at once would imply that we allow a firm to have innovation strategy based on frequent use of many different sources of information, but without any decision on activities that needs to be performed in the process; just to give an example how this would clearly not be a realistic representation of the reality.

Since coverage and response rate of the surveys differ between countries, the observations are weighted in the factor analysis to obtain unbiased results. For example, there are about 10,000 firms from Bulgaria but only 3,000 firms from Germany in the entire dataset; although the numbers of innovating firms in our sample seem to be somewhat more balanced (see Tables 8 below for composition of the sample by country). Size and industry distribution of these observations also differ from the target population. So we weight each observation by the inverse of the so-called sampling fraction, corrected for non-response and for no longer existing enterprises. In practice it means that we give higher weights to firms from underrepresented size categories, industries and countries. Only analysis that takes into account these weights provides representative results, which is an imperative for datasets with data for many countries.

Tables 1 to 5 provide results of the first stage estimates. We used principal axis factoring method to extract the factors (see SPSS 15.0 Manual for details of the procedure).[4] Only principal factors with eigenvalue higher than one were retained for rotation, which means that the last retained factor explains higher proportion of variance than an original variable (more than a reverse value of the number of variables). Solutions based on this criterion also proved to be consistent with the scree test (see Appendix 1 for overview of the eigenvalues). Before the results are interpreted, it is necessary to rotate the solution. We used the standard varimax rotation, which maximizes the sum of variances of squared loadings across the factors. It should be finally noted that the coefficients reported in the tables are so-called factor loadings, which are used to interpret the principal factors. A factor loading is coefficient of correlation between the new latent variable (columns) and the original variable (rows). If we flip the coin, the loading indicates the proportion of variance of the original variable that is accounted for by the principal factor.

Table 1 gives results of factor analysis on different innovation activities performed by firms. We have detected three principal factors. The first factor labelled "R&D" loads highly on both internal R&D and sourcing of R&D from external sources, which confirms their complementary role in the innovation process rather than "make or buy" decisions of firms along these lines (Veugelers, 1997; Veugelers and Cassiman, 1999). Another principal factor that has been detected correlates with training, but even more with market introduction of innovations and resources devoted to design and other preparations, so that this aspect has been labelled "Market-

[4] Maximum likelihood factoring requires multivariate normality of the data, which is clearly not a viable assumption for our dataset with binary and Likert scale variables. A major advantage of principal axis factoring is that this extraction method is not based on any distributional assumption.

ing". And the third dimension in the data mainly refers to acquisition of technology embodied in capital goods, acquisition of other external knowledge and not surprisingly training of personnel that is often necessary to put these external inputs into effective use. For a lack of a better word, we name this factor "External". Overall what comes out is on one hand a straightforward distinction between R&D-centred and other innovation activities and on the other hand a difference between innovation based on internal capabilities and dominated by external inputs.

Table 1: Factor analysis on variety of innovation activities

	(1) R&D	(2) Marketing	(3) External
Internal R&D	0.52	0.15	-0.12
Acquisition of extramural R&D	0.54	0.06	0.16
Acquisition of machinery and equipment	-0.10	0.03	0.41
Acquisition of other external knowledge	0.14	0.07	0.32
Training	0.13	0.55	0.31
Market introduction of innovations	0.13	0.76	0.01
Design and other	0.09	0.68	0.03

Note: Estimation weighted by the inverse the sampling fraction, corrected for non-response and for no longer existing enterprises; number of observations is 13,035; three factors with eigenvalue > 1 were detected, which explain 62.8% of total variance; extraction method: principal axis factoring; rotation: varimax with Kaiser normalization.

Table 2 report results of the factoring procedure on the effect of innovation. A clear distinction between three groups of effects related to introduction of "Product" as compared to "Process" innovations and the "Other" effects has been identified. Not all firms introduce product and process innovations simultaneously (although many of them do), so that it is not surprising to find this distinction in the effects. It is also a reason, why we do not use separate dummies for the occurrence of product and process innovations in the analysis, since this information is already picked up by the different effects and these dummies are therefore redundant. If added to the factor analysis along to the effects, the product and process dummies would tend to lead into the "inflated factors", which should be avoided as mentioned above.

Table 2: Factor analysis on effects of innovation

	(1) Product	(2) Process	(3) Other
Increased range of goods or services	0.75	0.04	0.02
Increased market or market share	0.77	0.11	0.06
Improved quality in goods or services	0.43	0.23	0.18
Improved production flexibility	0.17	0.71	0.13
Increased production capacity	0.10	0.79	0.15
Reduced labour costs per produced unit	0.08	0.75	0.19
Reduced materials per produced unit	0.13	0.61	0.35
Environmental, health and safety aspects	0.05	0.22	0.87
Met regulations or standards	0.13	0.21	0.60

Note: Estimation weighted by the inverse the sampling fraction, corrected for non-response and for no longer existing enterprises; number of observations is 13,035; three factors with eigenvalue > 1 were detected, which explain 69.1% of total variance; extraction method: principal axis factoring; rotation: varimax with Kaiser normalization.

Table 3 looks at relations between importance of the various sources of information for innovation. It comes out that there is a separate principal factor for "Science", which mainly puts together information from the university sector and from research institutes. Also this factor loads modestly to information from professional conferences, meetings and a journal, which is reassuring, because these are the devices though which firms communicate with academics and researchers. The second principal factor is driven mainly by information from clients or customers, but correlates also to information from competitors and from inside of the firm. All of these sources are in the business domain, so that we label this dimension as "Market" sources of information. And the third factor is given primarily by information from fairs and exhibitions and from the professional sources, so that it is identified as "Events", although it seems to be also somewhat related to the role of information from competitors and suppliers. It is interesting to find out that the latter source has not showed up strongly in the results, which would support a supplier-dominated information channel, but support for such as prediction is simply not supported by the data.

Table 3: Factor analysis on sources of information for innovation

	(1) Science	(3) Market	(2) Events
Within the enterprise	0.11	0.22	0.06
Suppliers	0.06	0.07	0.24
Clients or customers	0.05	0.86	0.08
Competitors or firms in the same industry	0.10	0.45	0.27
Universities and other higher education	0.79	0.15	0.15
Government or non-profit research institutes	0.64	0.12	0.14
Professional conferences, journals, etc.	0.29	0.16	0.53
Fairs and exhibitions	0.05	0.11	0.81

Note: Estimation weighted by the inverse the sampling fraction, corrected for non-response and for no longer existing enterprises; number of observations is 13,035; three factors with eigenvalue > 1 were detected, which explain 58.6% of total variance; extraction method: principal axis factoring; rotation: varimax with Kaiser normalization.

Table 4 shows result of the factor analysis on methods of protection. Only two principal factors came out, which conform to the distinction between formal and informal method of protection. The first factor on the "Formal" methods loads primarily on patents, design patterns and trademarks, while the second factor on the "Informal" methods correlates most to secrecy, complexity of design and the lead-time advantages, although there is a certain overlap between them. However, some overlap is natural because for example the ability to developed technology at the frontier manifested by patents should be associated to lead-time advantages on competitors and vice-a-versa.

Table 4: Factor analysis on methods of protection

	(1) Formal	(2) Informal
Patents	0.54	0.16
Registration of design patterns	0.74	0.09
Trademarks	0.43	0.20
Copyright	0.22	0.25
Secrecy	0.19	0.73
Complexity of design	0.13	0.65
Lead-time advantage on competitors	0.22	0.74

Note: Estimation weighted by the inverse the sampling fraction, corrected for non-response and for no longer existing enterprises; number of observations is 13,035; two factors with eigenvalue > 1 were detected, which explain 55.5% of total variance; extraction method: principal axis factoring; rotation: varimax with Kaiser normalization.

Finally, the last estimate in the first stage of the factor analysis focused on the other important changes that occurred in the firm along introduction of the technological innovation. Table 5 reveals that all of these changes tend to be highly correlated to each other and collapse into a single principal factor. Only the aesthetic change (or other subjective changes) seems to be a bit different, however not enough to forge a separate factor in the estimate. We shall refer to this factor as the measure of "Non-technological innovation" in the following.

Table 5: Factor analysis on other important changes in the firm

	(1) Non-technological innovation
Strategy	0.65
Management	0.63
Organisation	0.61
Marketing	0.53
Aesthetic (or other subjective) changes	0.32

Note: Estimation weighted by the inverse the sampling fraction, corrected for non-response and for no longer existing enterprises; number of observations is 13,035; one factor with eigenvalue > 1 was detected, which explains 44.5% of total variance; extraction method: principal axis factoring; rotation: varimax with Kaiser normalization.

As anticipated above, in the next step we run a higher-order factor analysis on the latent variables – so-called factor scores – that have been derived from the previous lower-order estimates. Also we include the dummy on innovation cooperation, which is meant to complement the picture. Table 6 gives the results. Four distinct innovation strategies of firms have been identified as follows:

1) "Research-based" innovation strategy builds on internal R&D capabilities combined with acquisition of R&D from external sources, extensive use of information from universities and research institutes. Also firms that pursue this strategy tend to be frequently engaged in cooperative innovation (or R&D) projects with other firms and organizations.

2) "User-driven" innovation strategy is geared toward product effects; innovation activities are focused on introduction of new products on the market, design of these products and a small element of R&D; firms tend to be most sensitive to signals from the market (chiefly form clients and consumers) and interestingly this strategy also often involves the non-technological changes in the enterprise, such as implementation of new business strategy, organization or marketing.

3) "Extensive" innovation strategy is based on exploiting opportunities for innovation from diffusion of technology embodied in new capital goods and acquisition of existing technology from other organizations by purchase of rights to use patents, licenses or software, which needs to be supported by training of employees as another important element of success of this strategy. Unlike the former two strategies formal nor informal methods of protection are not used frequently, which is reassuring, because most of the knowledge used in this strategy tends to be either tacit or purchased on the market for technology.

4) "Social (corporate) responsibility" strategy is focused on meeting demands on environmental, health and safety aspects of business and/or meeting regulations or standards imposed on the business, and there is some bias towards process innovation (for overview of the concept of Corporate Social Responsibility see Carrol, 1999). Information from public meeting places such as professional conferences, fairs and exhibitions is used extensively, although information from universities and research institutes is also utilized to some extent. Firms with this strategy do not tend to use any methods of protection extensively.

Table 6: Hierarchical factor analysis (2nd stage) on innovation strategies

	(1) Research-based	(2) User-driven	(3) Extensive	(4) Social responsibility
R&D	0.57	0.25	-0.03	0.04
Marketing	0.11	0.48	0.14	0.00
External inputs	0.07	0.05	0.62	0.14
Product effects	0.09	0.63	-0.02	0.10
Process effects	-0.01	0.05	0.14	0.26
Other effects	0.14	-0.05	-0.04	0.43
Information from science	0.51	0.04	0.04	0.19
Information from market	0.07	0.40	-0.02	0.02
Information from events	-0.04	0.21	0.08	0.36
Formal protection	0.25	0.31	-0.05	0.06
Informal protection	0.32	0.31	0.04	0.01
Non-technological innovation	0.12	0.34	0.13	0.17
Innovation co-operation	0.49	0.09	0.09	-0.06

Note: Estimation weighted by the inverse the sampling fraction, corrected for non-response and for no longer existing enterprises; number of observations is 13,035; five factors with eigenvalue > 1 were detected, which explain 47.0% of total variance; extraction method: principal axis factoring; rotation: varimax with Kaiser normalization.

5. How much explain differences across industries and countries?

As we have seen, innovation strategies of firms can be with the help of factor analysis boiled down into four basic categories. However, how much is adoption of the particular innovation strategy given by firm-specific factors and how much of it is given by differences between sectors and countries? As the first step toward answering this question we look at patterns of these innovation strategies by sectors and countries. Tables 7 and 8 provide this overview. [5] Note that the factoring procedure involves standardization of the variables (deducting mean and dividing by standard deviation), so that the factor scores produced by the analysis are standardized variables (average of zero and standard deviation of one).[6] From this follows that average above (below) zero for the particular sector/country indicates bias towards (against) adoption of the innovation strategy.

Table 7 provides overview of the factor scores broken down by the standard industrial classification, which broadly follows alphabetical NACE, rev. 1.1 structure with 26 categories at two-digit level. [7] Sectoral patterns of the innovation strategies broadly conform the expectations. Sectors with the highest average scores on the research-based strategy include the chemical (including pharmaceutical) industry (23, 24), electronics (30-33), transport equipment (34, 35) and other machinery (29) as well as the sectors of R&D services and computer and related activities (72, 73). Many of these sectors are perceived as the best examples of the "science-based" manufacturing and knowledge-intensive services in the literature (Pavitt, 1984 and Archibugi, 2001).

A host of these sectors, particularly electronics (30-33) and the R&D and computer services (72, 73), also score highly in the user-driven strategy. However, there are many more service sectors that score above the average in the role of users in the innovation process; these include post and telecom (64), auxiliary financial services (67), the wholesale trade (51) and the sector of other services (74), which covers variety of consulting services such as architectural and engineering activities, technical testing, advertising or labour recruitment. Note that the close user-producer interaction has been often put forward as the particularly important aspect of innovation in services (Evangelista 2000). At bottom of ranking in this strategy are sectors that produce homogenous products, such as mining and quarrying (10-14), electricity, gas and water supply (40, 41), and land, water and air transport (60, 61, 62), which is reassuring.

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[5] All the presented averages are weighted by the inverse of the so-called sampling fraction, corrected for non-response and for no longer existing enterprises, and therefore representative for the target population.

[6] Since the factor analysis has been weighted (see above), the weighted averages of the factor scores for the total sample are equal to zero by definition (and therefore not reported in the tables).

[7] More detailed classification was not possible due to limited information of the sectoral breakdown in the micro-aggregated CIS3 dataset from Eurostat. Note that in many countries several related 2-digit industries have been aggregated together due to low number of observations and resulting concerns of confidentiality (such as for example in the mining and quarrying sector). For more details consult Eurostat (2006).

Table 7: Overview of innovation strategies by industry (weighted average)

NACE, rev. 1.1.	Research-based	User-driven	Extensive	Social Respon-sibility	Number of obser-vations
10, 11, 12, 13, 14	-0.14	-0.70	-0.14	0.14	143
15, 16	-0.20	-0.17	-0.08	0.19	1214
17, 18	-0.06	-0.13	-0.05	0.02	786
19	-0.22	-0.23	-0.11	0.01	167
20	-0.13	-0.23	-0.08	0.02	362
21, 22	-0.46	-0.21	0.18	0.12	570
23, 24	0.47	0.07	-0.24	0.21	731
25	-0.02	0.01	-0.12	0.06	488
26	0.20	-0.33	-0.16	0.12	484
27, 28	0.00	-0.02	-0.06	0.13	1,023
29	0.28	0.16	-0.13	0.03	903
30, 31	0.23	0.29	-0.05	0.03	456
32	0.31	0.16	0.07	0.02	244
33	0.46	0.47	0.05	-0.07	284
34, 35	0.32	0.04	-0.01	0.07	513
36, 37	-0.28	-0.03	-0.09	0.19	638
40, 41	0.15	-0.55	0.14	-0.06	228
51	-0.19	0.06	0.05	-0.06	987
60, 61, 62	-0.05	-0.43	0.13	0.03	285
63	-0.12	-0.13	0.25	-0.04	264
64	0.04	0.14	0.03	-0.22	145
65	-0.10	-0.07	0.05	-0.34	281
66	0.09	-0.01	0.20	-0.48	189
67	-0.24	0.15	0.04	-0.42	88
72, 73	0.29	0.35	-0.09	-0.24	1,030
74	0.15	0.13	0.20	-0.17	532

Note: Average weighted by the inverse the sampling fraction, corrected for non-response and for no longer existing enterprises

The main defining feature of the extensive strategy is innovation based on purchase of "ready-to-use" technology embodied in capital goods or acquisition of existing technology thought licensing and other means. Hence we should expect sectors in which firms tend to maintain limited internal capabilities for technological innovation to come out with the highest scores on this strategy, which seems to be supported by the facts. At the top of the sectoral ranking in this strategy are auxiliary transport activities (63), the other services (74), insurance services (66), manufacture of pulp, paper and paper products (21, 22), electricity, gas and water supply (40, 41), and land, water and air transport (60, 61, 62). Despite limited R&D efforts, firms in many of these sectors are known to maintain extensive absorptive capabilities that fall just short of (or on the borderline) the definition of formal R&D and/or other than strictly technological capabilities for innovation. Also it is interesting to note that although we do not have any direct evidence on this in the dataset, it is likely that a lot in this strategy has to do with implementation of ICT technologies (particularly in services).

At the top of the social (corporate) responsibility composite should appear sectors with high concerns about the impact of their core business on health, safety and environment. As can bee seen from the table, the highest averages have been recorded for the chemical (including pharmaceutical) industry, manufacturing of food, products, beverages and tobacco (15, 16), recycling and other manufacturing (36, 37) and mining and quarrying (10-14), which is well in line with the expectations. On the other side of the spectrum are the financial, insurance and related services (65, 66, 67), the R&D and computer services (72, 73) and post and telecommunications (64), which activities seldom have a direct impact along these lines.

Table 8 shows how innovation strategies differ across countries. Firms in Norway, Lithuania, Belgium, Latvia and Estonia tend to have the highest score on the research-based strategy, while firms Portugal, Spain, Greece, Bulgaria and Romania the lowest tendency to adopt this strategy. A closer look at the underlying numbers shows that the somewhat surprisingly high score in the Baltic countries is based chiefly on frequent cooperation on innovation, which reveals important aspects of national innovation systems in this region. Only Germany and the Czech Republic came out with above average score on the user-driven strategy, while Spain, Lithuania and Portugal came out with low score. Germany, Portugal and the Baltics appear with high score on the extensive strategy with the Czech Republic, Bulgaria and Norway down on the list. It is difficult to interpret these results, apart from perhaps the fact that the industrial structure and idiosyncratic country effects may have played a major role here. And finally firms in Romania, Spain, Greece and Portugal seem to be the most concerned about the social (corporate) responsibility strategy, which suggest that this strategy at least partly reflects an attempt to catch up with the European standards along these lines.

Table 8: Overview of innovation strategies by country (weighted average)

Country	Research-based	User-driven	Extensive	Social respon-sibility	Number of observations
Belgium	0.14	-0.12	-0.18	-0.09	705
Bulgaria	-0.19	-0.20	-0.20	0.04	724
Czech Rep.	0.05	0.02	-0.20	-0.07	943
Germany	0.03	0.18	0.07	-0.04	1,525
Estonia	0.09	-0.02	0.06	-0.08	650
Spain	-0.13	-0.23	-0.07	0.12	2,957
Greece	-0.16	-0.10	-0.04	0.11	349
Lithuania	0.33	-0.38	0.00	0.05	604
Latvia	0.12	-0.02	0.10	-0.05	404
Norway	0.35	-0.11	-0.30	-0.17	1,355
Portugal	-0.10	-0.43	0.05	0.09	729
Romania	-0.21	-0.11	-0.09	0.19	1,736
Slovakia	-0.02	-0.23	-0.03	0.04	354

Note: Average weighted by the inverse the sampling fraction, corrected for non-response and for no longer existing enterprises

Although many of these higher-level averages seem to fairly sensibly aggregate the firm-level evidence, a closer look at the data reveals that there is considerable variance of scores on these strategies within both sectors and countries. In other words, despite the central tendencies at the sectoral and country levels make sense, which confirms that the results are feasible, there seems to be a lot of variety across firms that tends to be "averaged out" in the tables above. To find out how much variance in the innovation strategies is accounted by each level of the analysis; we estimate the so-called mixed-effects model on the data (which is sometimes also called random coefficient model, hierarchical model or simply multilevel model).

Since we have cross-classification of firms nested simultaneously within sector and countries, we need to partition the total variation of innovation strategies as the sum of contributions from firms, sectors and countries. A cross-classified mixed-effects model is the appropriate framework of the analysis in order to obtain estimates for the various variance components in this partition (Goldstein, 2003 and Hox, 2002).[8] So how much of the differences in innovation strategies among firms can be attributed to the higher level factors? And how much is given by idiosyncratic characteristics of firms?

If data have the cross-classified structure, observations from the same group are generally more similar than observations from different groups, which violates the assumption of independence in conventional regression models. In order to relax this assumption, we specify a basic mixed-effects model in which we introduce residual terms (errors) that are specific to each hierarchical level of the analysis. Consider a

[8] It should be noted that the total variance can be partitioned by using this method only for normally distributed variables. An important advantage of using factors analysis in this context is that the outcome variables – the factor scores for the four innovation strategies – are very close to be normally distributed (despite they are based on binary and/or Likert scale variables).

cross-classified structure, where the firm represents level-1 and the industry and the country are the higher levels of the analysis. The cross-classified nature of the problem can be delineated by the following:

Level 1: $y_{ijk} = \beta_{0jk} + r_{ijk}$
Level 2: $\beta_{0jk} = \gamma_0 + u_{00j} + v_{00k}$

where y is the dependent variable (the factor score on innovation strategy), i is the firm, j is the industry, k is the country, β_{0jk} is the level-1 intercept in level-2 unit jk; γ_0 is the mean value of the level-1 dependent variable, r_{ijk} is the unmodeled variability (error) for unit i, u_{00j} is the unmodeled variability (error) for unit j, and v_{00k} is the unmodeled variability (error) for unit k. The subscript jk indicates that we allow the intercept β_{0jk} to vary independently across both sectors and countries. A critical aspect of the two-level model is that the level-2 equation implies that the level-1 intercept is a function of level-2 variability, so that we can treat the intercepts as outcomes of the industry and country levels.

By substituting the level-2 equation into the level-1 equation we arrive to a reduced form of the model:

Reduced: $y_{ijk} = \gamma_0 + u_{00j} + v_{00k} + r_{ijk}$

which is composed of a single fixed effect γ_0 and three random effects (r_{ijk} at level-1 and u_{00j} and v_{00k} at the higher levels). In our analysis, r_{ijk} is variability accounted to the firm-level, u_{00j} is variability between industries and v_{00k} is variability of the same dependent variable between countries. Since this model contains no explanatory variables, the random effects represent unexplained error variance. In other words, this model does not explain any variance in y, but only decomposes the variance of the dependent variables into three independent components.

Hierarchical models can become more complex if level-1 or level-2 predictors are introduced (Luke 2004). For our purpose; however, it is enough to estimate the simplest possible two-level model with no predictors outlined above. The only purpose of this so-called unconstrained or null-model, is to disentangle how much of the variance of the dependent variable can be attributed to level-1 as compared to level-2 part of the model, i.e. to the firm as compared to the industry and country levels. [9]

Since the mixed model splits the random effect between the different levels, we can calculate so-called intraclass correlation coefficients (ICC), which are defined as follows:

$$ICC_j = \frac{\sigma^2_{u00}}{\left(\sigma^2_{u00} + \sigma^2_{v00} + \sigma^2_r\right)} = \frac{u_{00j}}{\left(u_{00j} + v_{00k} + r_{ijk}\right)}$$

[9] It can be shown, that the null-model is equivalent to one-way random-effects ANOVA model (Luke 2004), where we assume that the group means are randomly varying. If we would add predictors only to the level-1 equation, the model becomes a random effects ANCOVA.

$$ICC_k = \frac{\sigma^2_{v00}}{\left(\sigma^2_{u00} + \sigma^2_{v00} + \sigma^2_r\right)} = \frac{v_{00k}}{\left(u_{00j} + v_{00k} + r_{ijk}\right)}$$

where σ^2_r is the variance of the of the firm-level errors r_{ijk}, σ^2_{u00} refers to the variance of the industry-level errors u_{00j} and σ^2_{v00} is the variance of the country-level errors v_{00k}, respectively.

The ICC indexes indicate the proportion of variance in the dependent variable explained by the grouping structure of the population. [10] In our analysis, the ICC refer to percentage of variance in innovation strategies that is explained by the industry and country, respectively. For example, if the ICC_j equals to 0.25 it means that industry accounts for 25% of the variability of the particular innovation strategy among firms.

Table 9 shows results of the cross-classified mixed-effects model with 26 industries and 13 countries (for definition of the higher level units see Tables 7 and 8). Since the intercept is different from zero only because this estimate is not weighted, let us focus on the random part of the model. [11] Our analysis leads to the conclusion that most of variance in innovation strategies is given by heterogeneity at the firm-level. Only small fraction of the variability is accounted by the industry (from 3.8% to 10.5%) and even less by the country (from 2.1% to 5.4%).

Table 9: Results of the mixed-effects model (26 industries and 13 countries)

	(1) Research-based	(2) User-driven	(3) Extensive	(4) Social responsibility
$Intercept_{ijk}$ (γ_0)	0.191***	-0.101	-0.009	0.021
	(0.069)	(0.066)	(0.041)	(0.042)
Random effects:				
Level-1 (r_{ijk})	0.573	0.470	0.440	0.348
$Intercept_{ij}$ (u_{00j})	0.052	0.058	0.018	0.029
$Intercept_{ik}$ (v_{00k})	0.036	0.027	0.013	0.008
Level-1 (*i*) firms	13,035	13,035	13,035	13,035
Level-2 (*j*) industries	26	26	26	26
Level-2 (*k*) countries	13	13	13	13
ICC_j	7.9	10.5	3.8	7.5
ICC_k	5.4	4.9	2.8	2.1

Note: *, **, *** denote significance at the 10, 5 and 1 percent levels.

[10] Also ICC can be interpreted as the expected correlation between two randomly chosen units that are in the same group (Hox 2002, pg. 15)

[11] HLM 6.04 statistical package was used to estimate the mixed-effects model. Note that one-way random-effects (nested) ANOVA with a single level-2 can be estimated in other statistical packages. However, for example Stata 9.2 imposes relatively severe restrictions on size of the sample given by in-build limits of the program on matsize (up to 11,000).

Since we have been able (given the data limitations) to distinguish twice as much industries as countries in the previous estimate, in the next step we merge some of the industries to see whether the results are robust to details of the classification at the different levels of the analysis. Table 10 gives results of the cross-classified mixed-effects model with 13 industries and 13 countries. The main difference is that the ICC index at the industry level for the user-driven strategy has more than halved, but otherwise the overall picture remains intact.

Table 10: Results of the mixed-effects model (13 industries and 13 countries)

	(1) Research-based	(2) User-driven	(3) Extensive	(4) Social responsibility
Intercept$_{ijk}$ (γ_0)	0.173**	-0.125**	-0.030	0.055
	(0.083)	(0.061)	(0.044)	(0.050)
Random effects:				
Level-1 (r_{ijk})	0.576	0.488	0.444	0.349
Intercept$_{ij}$ (u_{00j})	0.052	0.022	0.012	0.024
Intercept$_{ik}$ (v_{00k})	0.037	0.026	0.013	0.008
Level-1 (*i*) firms	13,035	13,035	13,035	13,035
Level-2 (*j*) industries	13	13	13	13
Level-2 (*k*) countries	13	13	13	13
ICC$_j$	7.8	4.1	2.6	6.3
ICC$_k$	5.6	4.9	2.8	2.1

Note: *, **, *** denote significance at the 10, 5 and 1 percent levels.

7. Conclusions

This paper has used a large firm-level database drawn from the third wave of the Community Innovation Survey (CIS) in Europe to assess firm-level heterogeneity in innovation strategies. We use the notion of innovation strategies to reflect the fact that the most important aspect of innovation at the firm level is how firms do innovation, and not (only) how much effort they devote to it. Our first research question was if and how the various aspects of innovation that the CIS captures can be combined into meaningful combinations that can be characterized as "innovation strategies". Using hierarchical factor analysis, we indeed found such innovation strategies.

The strategies we found are Research-based, User-based, Extensive and Social responsibility. The first of these, research-based, corresponds to the traditional view of the innovating firm being heavily dependent on (internal) R&D. We find that this innovation strategy also draws on interactions with science. The user-based strategy depends on knowledge from, and interaction with customers and clients, and focuses more heavily on product innovation and its support activities (marketing). The extensive innovation strategy is used primarily by firms that do not devote a large amount of resources to R&D, but get knowledge for innovation from generally accessible external sources. Finally the social responsibility strategy is aimed largely at environmental innovations and improving effects on health and safety. These results stress that an overemphasis on R&D, both by policymakers and scholars, is oversimplifying the matter. An innovation policy that is largely aimed at quantitative targets of R&D spending and the like will not capture the essence of innovation in many firms.

In analyzing our second research question, i.e., to what extent innovation strategies are specific to countries or industries, we found that firm-level heterogeneity is the dominating tendency in the data. Despite the work on sectoral taxonomies of innovation, or sectoral and national systems of innovation, these two dimensions – sectors and countries – only capture a minor part of the variance in the innovation strategies that we observe at the firm level. Within sectors and countries, a multitude of innovation strategies is observed. Although there are some regularities of innovation strategies by the (NACE) industries, there is even more variability within these industries. It is therefore very problematic to extrapolate anything about innovation strategy of a firm given its classification in a NACE category. Sectoral studies of innovation using aggregated data by the NACE classification of firms (including the work adopting the Pavitt taxonomy of sectors) might by largely oversimplifying the considerably heterogeneous picture at the firm-level. A similar argument may be made for the literature on national systems of innovation: we find considerable heterogeneity in firm behaviour even within a country/sector combination.

As a final cautionary note, we cannot conclude that there are no useful aggregation levels above the firm level. For instance, there might be different industrial classification that would be more relevant for explaining differences in innovation strategies across firms than the standard NACE, rev. 1.1 classification that we used, or there might be more regularities at lower levels of sectoral aggregation. With respect to the country-level, this may not be the most suitable geographical unit. Regions within countries may matter more. Hence, testing our research questions with different units of sectoral and geographical aggregation remains an important task.

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Appendix 1: Overview of eigenvalues before rotation

	1	2	3	4	5	6	7	8	9
1st stage:									
Innovation activities	2.01	1.18	1.13	0.85	0.70	0.60	0.46		
Effects of innovation	3.53	1.57	1.12	0.72	0.59	0.42	0.41	0.34	0.30
Sources of information	2.44	1.18	1.08	0.96	0.84	0.56	0.51	0.44	
Methods of protection	2.66	1.22	0.94	0.69	0.59	0.48	0.42		
Other changes	2.22	0.93	0.71	0.61	0.52				
2nd stage:									
Innovation strategies	2.53	1.32	1.25	1.01	0.93	0.89	0.85	0.80	0.76