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Technological Diversity and Future Product Diversity in the Drug Industry*

Uwe Cantner[†] Tatiana Plotnikova[‡]

May 2009

This paper deals with the topic of related R&D and innovation strategies of large firms. We ask what determines the diversity of a firm's product portfolio. More specifically, we try to explain large firms' expansion into new product markets driven by the characteristics of their technological knowledge. Empirically, we study firms in the pharmaceutical and biotech industries, using relevant data on product development and technological knowledge. We find a positive relationship between the diversity of a firm's future product portfolio and the diversity of its stock of technological knowledge. This relationship becomes weaker when the breadth of technological knowledge increases.

Keywords: Product diversity, technological diversity, product relatedness, technological relatedness, coherence

JEL Classification Number: O32, L25, L65

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1 Introduction

In his *Capitalism, Socialism and Democracy* (Schumpeter, 1942), Joseph Alois Schumpeter described the large multiproduct firm as a main driver of economic development. Such a firm has the financial means and organizational capacities to run its own laboratories, where research and development projects are initiated and managed, in order to maintain a systematic search for new knowledge and new ideas, as well as to facilitate their development into marketable products and executable processes.

The broad research question guiding this paper is the design of R&D and innovation strategies of Schumpeterian large firms, the determinants of their strategies, and the development of these strategies over time. In this general framework, we are concerned with a firm's current knowledge as well as its R&D projects as major determinants of its development. The knowledge represents a firm's intellectual capital and includes tangible and intangible knowledge, as well as the experience and skills of its employees.

In particular, this paper aims to explain large firms' expansion into new product markets driven by the characteristics of the technological knowledge held by them. We look at the product-in-development portfolios of firms which inform us about their planned future product portfolio. Product-in-development activities are part of firms' general R&D activities, which start just after invention (often related to patenting) and are pursued until the new idea is developed into a marketable product. Empirically, we examine firms in the pharmaceutical and biotech industries, using relevant data on product development and the technological knowledge involved. We find a positive relationship between the diversity of firm's future product portfolio and the diversity of its stock of technological knowledge. However, this relationship tends to become weaker when the technological breadth (the number of technologies pursued by the firm) increases. Contrary to our expectations, the relatedness of a firm's technological knowledge base shows no significant influence on the product portfolio diversity.

The paper proceeds as follows: In section 2, we discuss theoretical arguments on diversification in products and technologies, deriving some appropriate hypotheses. In section 3, we explain the methodology used in the empirical analysis; we introduce measures of diversity, variety, relatedness, and breadth as well as our data and variables. The presentation and discussion of our estimation results is contained in section 4. Section 5 summarizes and concludes.

2 Product and technology diversity

2.1 Why do firms diversify?

To answer this question with respect to the product diversity of a multiproduct firm, one has to refer to the determinants accruing from both the production or technology side and the demand side. Considered from the demand or market perspective, product similarity in terms of consumer characteristics (or markets) can cause competition among products (Dixit and Stiglitz, 1977). To avoid that competition with itself, a firm will try to diversify its product portfolio into different markets (Shaked and Sutton, 1990). Hence, the higher the degree of substitution between products in a firm's portfolio, the lower the number of products produced for the same market (Ju, 2003). Accordingly, firms should not diversify into the markets of similar products.

Although product similarity is attributed in these studies to some kind of market similarity, products can be similar also with respect to the knowledge which is embedded in them and used in their development and production. This embedded knowledge is drawn from a firm's knowledge stock, comprising the intellectual capital, i.e., tangible and intangible knowledge, experience and skills of the employees, and including technological knowledge, market knowledge, and organizational knowledge. This stock allows a firm to introduce and develop new products and defines its ability to introduce a diversified product portfolio.

Technological knowledge is one of the components of a firm's knowledge, which is considered one of the strategic resources in the sense of the resource-based view of the firm (e.g., Penrose (1959)). Strategic resources are defined as rare, valuable, rarely/not substitutable and rarely/not imitable. Technological knowledge, which also includes specialized knowledge related to the introduction and production of complex products, clearly represents one of the firm's strategic resources.

A firm's knowledge stock is built up over time, as mentioned in the dynamic capabilities approach (Teece, 1982; Teece et al., 1994). So the ability of a firm to introduce a new product depends on the firm knowledge development over time as well as on its ability to use its knowledge. A firm that successfully exploits its unique knowledge base generates new products such that they contribute to its competitive advantage.

According to Bierly and Chakrabarti (Bierly and Chakrabarti, 1996), several dimensions are relevant in the development of a firms' knowledge, specifically technological knowledge. First, firms are concerned with the speed of learning and building up a knowledge stock. Second, a major issue is "make-or-buy" in the sense of whether a firm should itself generate the knowledge necessary for a new product (internal R&D), buy

it from an external source (external R&D), or engage in cooperative arrangements (cooperative R&D). The third dimension concerns the breadth of a firm's knowledge base in the sense of how to allocate it in combination with R&D across different technologies and different markets - economies of scope and scale are relevant here.

Our paper is concerned with that third dimension: the spread of a firm's knowledge base across technologies and markets. Here we are particularly interested in the relationship between a firm's technological portfolio, or technological knowledge, and its portfolio of new products. With respect to the former, there is some evidence that larger firms tend to diversify their knowledge and R&D portfolios over a larger number of technologies (Granstrand, 1998). There is also evidence from other studies that exploiting economies of scope generated by this diversification may increase research productivity (Henderson and Cockburn, 1996). Hence, firms engage in related fields in order to exploit (firm internal) spillovers and economies of scope in R&D.

As this efficient use of technologies and knowledge is an important issue, we amend our argument by taking into account the diversity of a firm's knowledge stock. We expect to derive from that some additional insights into the question of how a multiproduct firm designs its product diversification depending on the available firm specific technological knowledge and its development over time.

To summarize, firms develop and produce a portfolio of products which are different with respect to the consumer market, but are similar with respect to the resources, including knowledge and technologies, used for production. Additionally, as far as the knowledge resources of a firm are concerned, evolving dynamic capabilities play an important role in the development and subsequent further diversification of its product portfolio.

2.2 The products and product portfolio of a multiproduct firm

Based on the discussion of the incentives and the capabilities for product diversification, we now introduce our concept for the products of a multiproduct firm and the respective portfolio of products.

As discussed, the similarity between products is often interpreted as one between demand characteristics (Ju (2003); Dixit and Stiglitz (1977); Shaked and Sutton (1990, 1987); Hotelling type models among others). On the other hand, similarity in the technologies is needed to develop and to produce (efficiently) distinct products. So the concept of a product in our study is quite complex, as it takes into account the demand as well as the technology side.

For this purpose, we consider a product in the context of a multiproduct firm in terms

of its relation to other products in the firm's portfolio. The respective relations to other products can be expressed in terms of an interaction between technology and demand in the following way. In the technological realm, products are more related to each other if the knowledge used to produce them is also more related (if not identical). In the demand realm, products are more related to each other if they share more common characteristics and are supplied to the same markets. In this sense, we look at a product from a firm perspective (in the interpretation of Penrose (1959) and Teece (1982); Teece et al. (1994)), taking into account the product characteristics relevant for market competition as well as the product-specific technological knowledge involved in production. This view is obviously different from an approach that is oriented purely to the demand side with respect to product characteristics (Lancaster, 1966; Saviotti, 2001) as well as from a purely production and scale-oriented, neoclassical approach.

Putting these arguments into a dynamic context, we consider changes in a firm's product portfolio, driven by product and technological relationships. A major role in this context is played by a firm's technological knowledge stock, as it is an important determinant of future product creation. A product can be considered a combination of different knowledge components, mainly technological ones. A broader spectrum and thus a greater variety and/or diversity of firm's technological knowledge implies that this firm faces more opportunities and provides more capabilities to develop a broader set of products. Moreover, if knowledge in different areas is developed rather evenly, it would be more profitable to produce a diversified product portfolio rather than specializing in only one field. Accordingly, a broader spectrum of a firm's technological knowledge implies that, in order to diversify its product portfolio further, the firm has to invest less in the development of new technological fields.

Product market similarities, such as marketing and distribution, also play a role in the creation of distinct products. The respective product market knowledge is part of a firm's resource base, which should be dealt with similarly to other resources. A firm's decision to generate and to supply a new product is governed also by the synergy effects related to marketing and distribution, as well as to the cost of becoming familiar with a new market. Hence, from this point of view, generating new products for similar or related markets seems to be preferred to generating new products for completely different markets. However, taking into account the competition aspect, markets for the same product (below called niches) are not expected to be most attractive for new product introduction.

Figure 1 schematically depicts our product conception in the context of a multiproduct firm. Product 2 is defined in terms of its relation to products 1 and 3. The relation to

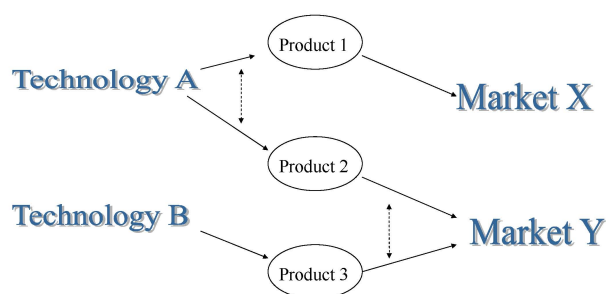


Figure 1: Product relations of a multiproduct firm

product 3 is defined according to market similarity, whereas the relation to product 1 is of a technological nature. This implies that expanding into the market of product 2 will be motivated both by technological and market relatedness. Here the relatedness between products 2 and 3 markets implies the joint effect of market knowledge (which allows economies of scope) and competition (which provides negative incentives to enter similar markets) on the possible gains from product expansion.

Summarizing, we note that firms prefer related markets and technologies when choosing the direction of their product development. Accordingly, the development of a new product requires similar technological knowledge or contributes to related markets, or both. The choice of product 2 from Figure 1 can be motivated both by technological and product market relation.

Extending this discussion of new product design from the level of a product to the level of product portfolios requires characterizing such portfolios in terms of market relationships as well as technological relationships among products and technologies. In this sense, a firm's product portfolio is first characterized by the variety and the diversity with respect to the products it comprises. Looking at this portfolio from the market side, measures of the relatedness of its products in terms of product market similarities (where we distinguish between sub-markets and niches) can be used. An equivalent characterization can be performed for the technology side of the portfolio when taking into account the features of technological knowledge. Here a technological portfolio is characterized by diversity, coherence, and breadth of the technological knowledge, which is required to generate and to produce the portfolio's products. Figure 2 shows these

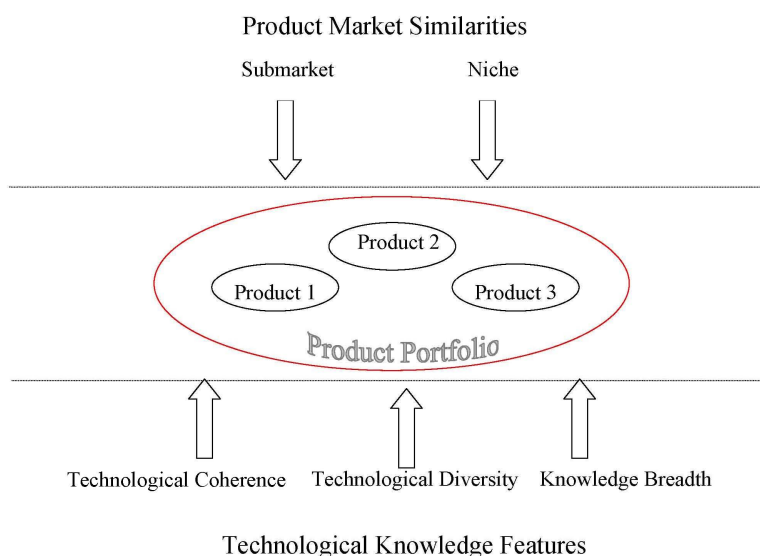


Figure 2: The determinants of product portfolio diversity

relationships for the case of product portfolio consisting of three products.

Diversity characterizes the extent to which the portfolio is comprised of different products and technologies, respectively. Coherence aims at the intensity of connections between the elements in a portfolio. Respectively, breadth accounts for the spread of the knowledge among different fields.

2.3 Hypotheses

Based on the arguments introduced above, we are interested in the relationship between the diversity of a firm's product portfolio, on the one side, and technological knowledge features on the other. We also expect product market experience to play an important role in the diversification decision. We suggest two hypotheses, to be tested below.

A multiproduct firm selects new products to be developed in accordance with its technological resources and capabilities. These resources and capabilities reflect the technological knowledge crucial for developing new products. We expect a more diverse technological knowledge base to allow capturing more diverse market opportunities. In this context, according to evidence documented in Gambardella and Torrisi (1998) for the electronics industry, technological diversification of the firm is broader than product diversification. A similar finding is reported by Patel and Pavitt (1997) in their study of

large multinationals. What these findings suggest is that, although broader knowledge allows capturing more opportunities (Breschi and Malerba, 1999), this relationship seems to diminish by the degree of increase in the knowledge base of a firm. Hence, with an increasing knowledge base, we expect a reduced effect of technological diversity on product diversity. This can be explained by the reduced need to add new distinct technologies in order to develop diverse products. The following hypotheses attempts to test these logics:

Hypothesis 1a: A firms' technological diversity and knowledge breadth in $t-1$ positively affects its product diversity in t .

Hypothesis 1b: A broader knowledge base of a firm in $t-1$ reduces the effect of that firm's technological diversity in $t-1$ on its product diversity in t .

Another determinant of product diversity is the coherence of knowledge. A more coherent portfolio is associated with higher diversity, due to economies of scope. Economies of scope can be partly explained by the fact that technological knowledge pieces are related (Breschi et al. (2003); Silverman (1999) among others) and partly by some other similarities between products. So, the second hypothesis is formulated as follows:

Hypothesis 2: The diversity of firm product portfolio at time t is positively correlated with the coherence of that firm's technological knowledge stock in $t-1$.

3 Methodology

3.1 Measures

Diversity

To define diversity, we have to distinguish between variety and diversity. Variety is usually referred to as overall number of items (Saviotti, 2001), whereas diversity is often meant as some combination of variety, disparity and balance characteristics of a group of items (Stirling, 1998).

The important component of diversity, which is not reflected by simple counting of items, is the distribution of different items (or their shares) in a portfolio. Taking into consideration shares of items accounts for disparity and balance. Obviously, a portfolio which is more concentrated is less diverse than a portfolio with an even distribution of items.

To give an example, a firm has experience in two technologies, say automobiles and construction, yet it has more experience in one technology, for example in construction, than in the other. This firm will then be more specialized in the technology where it has more experience (in our example this is construction), and so will be less technologically diverse than a firm with equal experience in both technologies.

The so-called measure of "effective diversity" proposed by Baumgaertner (2004) is a quite convenient measure. It accounts for different items in the portfolio weighted by the number of appearances of a particular item. That is, the effective diversity measure calculates the unevenness of the contribution of different items to a portfolio. As a result, this measure is highest when all items in a portfolio have the same number of occurrences. The bigger the distances between the items' numbers of occurrences, the lower the coefficient.

Formally, the effective diversity measure is calculated as follows:

$$v_{\alpha}^n(s) = \left\{ \begin{array}{l} (\sum_{i=1}^n s_i^{\alpha})^{1/(1-\alpha)}; \alpha > 0, \alpha \neq 1 \\ \lim_{\alpha \rightarrow 1} (\sum_{i=1}^n s_i^{\alpha})^{1/(1-\alpha)}; \alpha = 1 \end{array} \right\} \text{ for all } n \in N \quad (1)$$

where α is the order of entropy, n is the total number of different items, and s_i is the share of items i in all items.

Depending on parametrization, i.e., on the choice of α , this statistic produces various measures of diversity. With $\alpha = 0$ this measure simply counts the number of groups of items (variety). With an increasing value of α , more weight is put on the uneven distribution of number of items in groups.

In our analysis below, we at first use $\alpha = 2$, implying a measure for diversity, as we want to take into account the degree of specialization among products or technologies. The respective variable representing product diversity is ProdDiv and the one for technological diversity is TechDiv. Second, we use $\alpha = 0$, which refers to variety as measured by the number of products and technologies, respectively. The variable for products is labeled ProdVar and the one for technologies TechVar.

Coherence

The degree of relation between elements of portfolio can affect both technological (Breschi and Malerba, 1999; Breschi et al., 2003) and product (Baysinger and Hoskisson, 1989; Geraud-Heraud et al., 2003; Ju, 2003; Kay, 2002; Nesta and Saviotti, 2005; Teece et al., 1994) diversification choices. Moreover, the literature on product diversification (e.g. Piscitello (2000)) suggests that coherence is determined by industry level as well as by firm-specific characteristics. So, we intend to include coherence in our estimation.

In measuring product and technological coherence, we follow Teece et al. (1994). Two products/technologies are considered to be related if their joint appearance in firms' portfolios/patents is not accidental. So, the relatedness between them is the deviation from a random distribution. Here a random pairwise co-occurrence follows a hypergeometric distribution. So, we need to compare the actual number of pairwise co-occurrences of products/technologies in a firm's product/technological portfolio with a random number generated from a hypergeometric distribution with mean μ_{ij} and variance σ_{ij}^2 .

Equation (2) represents the probability that products/technologies i and j appear in the same portfolio/same patent for technologies:

$$\mu_{ij} = E(X_{ij} = x) = \frac{O_i \cdot O_j}{K} \quad (2)$$

Here K represents the population size (number of firms), O_i is number of products/technologies of type i and O_j is number of products/technologies of type j .

$$\sigma_{ij}^2 = \mu_{ij} \left(\frac{K - O_i}{K} \right) \cdot \left(\frac{K - O_j}{K - 1} \right) \quad (3)$$

σ_{ij}^2 is variance of a hypergeometric distribution with parameters K , O_i and O_j .

If the actual number of co-occurrence of two products/technologies in one firm portfolio (in patents for technologies) deviates from its expected mean, these products/technologies are related. Their relatedness is calculated as τ_{ij} :

$$\tau_{ij} = \frac{J_{ij} - \mu_{ij}}{\sigma_{ij}^2} \quad (4)$$

where J_{ij} is actual number of co-occurrences of products/technologies i and j in one portfolio.

The next step is to calculate the relatedness coefficient of the portfolio of a firm. This is done by weighting a firm's product/technology portfolio by the pairwise relatedness τ_{ij} . The weighted average relatedness (WAR_k) of firm k 's portfolio is the result of this calculation:

$$WAR_k = \frac{\sum_{i \neq j} \tau_{ij} P_{kj}}{\sum_{i \neq j} P_{kj}} \quad (5)$$

where P_{kj} is number of products/technologies j in firm k 's portfolio.

The vector WAR_k contains the average relatedness of each product/technology to all other products/technologies for firm k . Eventually, the coherence (Coh_k) of a firm's k product/technological portfolio is the sum of the vector WAR_k elements weighted by

the share of each product/technology:

$$Coh_k = \sum \left(\frac{P_{ki}}{\sum_i P_{ki}} W AR_{ki} \right) \quad (6)$$

For our analysis, the coherence is calculated both with respect to products and to technologies. For products, we calculated three measures of coherence: (1) coherence in niches (indications), considering the co-occurrence of indications in firms' product portfolios (ProdCoh); (2) coherence in submarkets, considering the co-occurrence of therapeutic areas in firms' product portfolios (ProdCohSub); (3) coherence of approved products in submarkets (ProdCohAppSub). The first two measures refer to products in development, whereas the third measure looks at already approved products.

Our measure for technological coherence is based on the co-occurrence of four-digit IPC codes in a firm's patents (TechCoh).

Technological breadth

The measure of technological breadth simply counts the number of different classes or groups weighted by the total number of technologies a firm is able to apply. In our study, the breadth of technology is measured by using patent data. Each patent indicates IPC (International Patent Classification) codes assigning specific technology fields to that patent. The main classification of a patent, together with the supplementary IPC codes, allows us to proxy the breadth of the codified knowledge (e.g., Nesta (2007)). In our case, the breadth of firm technology is the number of different IPC codes on four-digit level a firm addresses in its patents divided by the total number of technologies. The variable we constructed that way is labeled TechBreadth.

3.2 Data and Variables

Our investigation requires the combination of both technological knowledge and products-in-development characteristics. For this purpose, the data set employed in the current study originates from two sources: the listings of currently developed drugs by BioPharm Insight and the European Patent Office (EPO) database. The former dataset is used to construct variables which describe the products in the product-in-development portfolios of firms. The latter database is used to account for the technologies and the implied technological knowledge being used to develop and to produce these products.

The information on products-in-development was obtained from the website of BioPharm Insight (publicly accessible website). Until the end of 2007, the website gave

information on drugs in development. The various stages already taken in the development of a specific drug are listed in this database. The drugs are grouped by indication (the area of application or disease), where we interpret each indication as a product niche.

Indications are grouped into therapeutic areas, submarkets in our interpretation. We have 260 indications grouped into 17 therapeutic areas. Using a niche definition of a product suggests that we consider product diversification among product niches. Products in the same niche are taken to be identical. (In our sample, products in the same niche treat a particular disease or indication.) The additional information on approved products was acquired from the BioPharm Insight website as well. Approved drugs are classified only by therapeutic areas. The dataset we address consists of roughly 2500 firms all over the world with data on drugs in development from 1982 to 2007.

The patent data base provided by the European Patent Office is expected to reflect characteristics of firm technological knowledge. The database contains European and worldwide patents, with WO/78/000001-2007/150079 (19. Dec. 1978 -27. Dec. 2007) as worldwide patents and EP-A-0000001-1871158 (20. Dec. 1978 -26 Dec. 2007) as European patents. From this database, we use only patents assigned to the firms from the products-in-development database. Then the IPC codes on the four-digit level are used to represent distinct streams of a firm's technological knowledge. A technology is defined according to patent classification. Here, technologies with different four digit IPC codes are considered to be different.

For our regression analysis, we use fixed effects regression which allows us to control for possible firm internal characteristics which cannot be controlled for in OLS regression. We distinguish between two designs. In the first, the diversity design, we focus on diversity, and so, on the product as well as the technology side, the respective diversity measures with $\alpha=2$ are used. In the second design, the variety design, we simply look at variety, and so the relevant diversity measures are computed with $\alpha=0$. Accordingly, the dependent variable is either product diversity $ProdDiv(t)$ at time t in the diversity design or product variety $ProdVar(t)$ at time t in the variety design.

Most of the explanatory variables are lagged by one period and computed as stock variables covering the respective past five years. The variables of interest for hypothesis 1a are technological diversity, $TechDiv5(t-1)$ (diversity design) and $TechVar5(t-1)$ (variety design), respectively, as well as technological breadth $TechBreadth5(t-1)$. Here we expect a positive sign, suggesting that technological diversity and breadth positively affect product diversity. Testing hypothesis 1b, we use the technology breadth variable, $TechBreadth5(t-1)$ and diversity variable $TechDiv5(t-1)$. We additionally use an interac-

tion variable (Interaction), taking into account the effects accruing from the interaction between technological diversity $TechDiv5(t-1)$ (or $TechVar5(t-1)$ in variety design) and technological breadth $TechBreadth5(t-1)$. For hypothesis 1b to be not rejected, the coefficient of the technological diversity measure should be positive and that of the interaction negative. In the variety design, this interaction variable is computed between $TechVar5(t-1)$ and $TechBreadth5(t-1)$. The variable of interest for the hypothesis 2 is coherence in technology, $TechCoh5(t-1)$. If the coefficient on $TechCoh5(t-1)$ is positive and significant, hypothesis 2 cannot be rejected.

The similarities between the elements of the current products-in-development portfolio can also explain products-in-development diversity. Moreover, similarities between products can be disaggregated to the sub-market and niche level (following Piscitello (2000)). So, in order to control for market similarities in the portfolio choice, we add into our regression variables representing product relatedness with respect to niches ($ProdCoh(t)$) and relatedness of products-in-development with respect to submarkets ($ProdCohSub(t)$). According to previous studies and to our intuition, the coefficients on these variables are expected to be positive. To control for path dependency in the diversification strategy, the diversity of approved product portfolio $AppProdDiv5(t-1)$ as well as the diversity of the products-in-development portfolio in the past $ProdDiv5(t-1)$ are included. Sales in the previous period $Sales(t-1)$ are used to proxy a firm size effect on diversity. Controlling for structural breaks, we include also two dummy variables related to the years 1998 and 2002.

Testing the two hypotheses for the diversification design, a linear fixed effects regression model is used. In the variety design, the dependent variable is a count variable. Hence, we apply a fixed effect negative binomial regression approach.

4 Estimation

4.1 Diversity design

The first step in the estimation related to the diversity design is a variable analysis. Table 1 contains descriptive statistics of the data we intend to include into estimation.

It is clear from the descriptive statistics and the correlation table of variables (Table 8 in the Appendix) that these variables do not follow a normal distribution. Most of them are skewed. Given that most of the products are developed by big firms, there have to be some internal firm characteristics which have to be controlled for in order to receive unbiased estimators. This seems to be true, as variables are less skewed after controlling for fixed effects ((Table 2 and Table 9 in the Appendix deliver descriptive

Table 1: Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
ProdDiv(t)	112	8.813857	8.415552	1	34.57231
TechDiv5(t-1)	112	2.849819	1.301051	1	6.443299
TechBredath5(t-1)	112	0.4242822	0.361992	0.0196721	1
TechCoh5(t-1)	112	0.4814594	0.743412	-1.085976	3.648247
ProdCoh(t)	112	3.245607	2.91988	0	26.59358
ProdCohSub(t)	112	0.6319689	0.3531375	0	1.224365
AppProdDiv5(t-1)	112	4.156309	2.472193	1	10
ProdDiv5(t-1)	112	15.43687	13.11659	1	47.62533
Sales(t-1)	112	583.1909	797.2488	0.1475709	3983.009

Variables description can be found in the Appendix.

Table 2: Descriptive statistics, corrected for firm fixed effects

Variable	Observations	Mean	Std. Dev.	Min	Max
ProdDiv(t)	112	8.813857	4.818674	-3.822883	26.79525
TechDiv5(t-1)	112	2.849819	0.7155545	0.8498192	4.849819
TechBredath5(t-1)	112	0.4242822	0.1398347	0.0909489	0.8131711
TechCoh5(t-1)	112	0.4814594	0.2472771	-0.3961471	1.847156
ProdCoh(t)	112	3.245607	2.523139	-3.945081	22.6485
ProdCohSub(t)	112	0.6319689	0.2630352	-0.0645703	1.222149
AppProdDiv5(t-1)	112	4.156309	0.6126676	2.56502	6.523925
ProdDiv5(t-1)	112	15.43687	7.67202	-10.96456	39.15746
Sales(t-1)	112	583.1909	102.443	308.345	1010.044

Variables description can be found in the Appendix.

statistics and correlation analysis after controlling for unobservable fixed effects). We also performed a Hausman test, suggesting that a fixed effects model is the appropriate estimation strategy.

The fixed effects estimation results of the linear model (diversity design) are presented in Table 3, with the dependent variable ProdDiv(t) as products-in-development diversity.

We distinguish models 1-4, which differ in the way they account for the change in unobservable variables over time. Model 1 does not take into account possible time effects at all. Models 2 and 3 assume that there was a structural break in the year 1989 and the year 2002, respectively. These two years were suggested by looking at the development of the product and the technology related variables we use in our approach. Model 4 includes time dummies for all years from 1986 to 2007.

Table 3: Estimation Results. Dependent variable: Product diversity

	1	2	3	4
	fe	fe	fe	fe
		y98	y02	year dummy
TechDiv5(t-1)	2.132** (1.018)	2.440* (1.239)	1.953* (1.009)	2.367** (0.929)
TechBreadth5(t-1)	1.686 (3.955)	2.18 (4.475)	2.295 (3.775)	2.101 (4.113)
Interaction	-3.413** (1.488)	-3.579** (1.582)	-2.756* (1.513)	-3.042** (1.307)
TechCoh5(t-1)	2.361 (1.82)	2.485 (1.985)	1.847 (1.501)	1.744 (1.812)
ProdCoh(t)	0.202 (0.128)	0.177 (0.115)	0.137 (0.105)	0.0927 (0.11)
ProdCohSub(t)	5.315*** (1.778)	4.812*** (1.621)	3.823** (1.383)	2.742* (1.412)
AppProdDiv5(t-1)	-1.267 (0.87)	-1.463 (1.054)	-1.518 (0.912)	-1.219 (1.085)
ProdDiv5(t-1)	0.0697 (0.136)	0.0456 (0.137)	-0.022 (0.148)	0.0822 (0.181)
Sales(t-1)	0.0189** (0.00709)	0.0194** (0.00708)	0.0163** (0.00728)	0.0173** (0.00751)
y98		7.050** (2.694)		
y02			5.064** (2.353)	
Constant	-6.53 (4.744)	-13.22** (5.584)	-5.774 (5.464)	-13.40** (5.75)
Observations	112	112	112	112
Number of firm	25	25	25	25
R-squared	0.5	0.515	0.544	0.613

Robust standard errors in parenthesis.

* significant at 10%; ** significant at 5%; *** significant at 1%.

For all four models, let us first have a look at the control variables we use for market similarities in the portfolio choice, for path-dependency and for firm size effects. We find no significant effect of path-dependency in a firm's products-in-development diversity (AppProdDiv5(t-1), ProdDiv5(t-1)). For market similarities in the portfolio choice, we find a significant positive effect only on the broader level of submarkets (ProdCohSub(t)), not on the rather narrow level of niches (ProdCoh(t)). Hence, a firm's degree of products-in-development diversity is positively dependent on its current products' coherence with respect to submarkets. A current coherence of a firm's market niches, however, does not significantly influence its degree of products-in-development diversity. The presumption that the degree of product diversification of a firm is mainly dependent on firm size is taken into account by the variable Sales(t-1). The coefficient throughout is positively significant, justifying our presumption on firm size effects.

Let us now look at our two hypotheses. Hypothesis 1a suggests a positive relationship between a firm's products-in-development diversity and its technological diversity, as well as its technological breadth, which is partly confirmed for models 1-4. The coefficient on technological diversity (TechDiv5(t-1)) is positive and significant in all models. According to hypothesis 1a, the coefficient of the technological breadth (TechBreadth(t-1)) measure has to be positive as well. However, we do not find significant results for this coefficient. That implies that a knowledge stock consisting of a larger number of different technologies in (t-1) is not directly connected to a more diversified product portfolio in (t). So, the test of hypothesis 1a suggests that the diversity but not the breadth of a firm's technological portfolio is positively connected to future products-in-development diversity.

For all four models, hypotheses 1b cannot be rejected. As already hinted at, the coefficient of technological diversity (TechDiv5(t-1)) is positive and significant, implying that a firm showing a more diversified stock of technological knowledge in (t-1) runs a more diversified portfolio of products in (t). That is, technological diversity in the past allows a firm to pursue a more diversified development strategy. Although we did not find a significant direct impact of technological breadth on product diversity previously, hypothesis 1b assumes an indirect effect captured by the interaction term. The interaction term measuring the joint effect of technological breadth and technological diversity on product diversity is significantly negative in all four models. As hypothesis 1b is not rejected, we can claim a significant indirect (through technological diversity) connection between technological knowledge breadth and product diversity. Hence, possessing a more broad technology reduces the impact of technological diversity on products-in-development diversity. Our interpretation of this result is that, for firms

applying technological knowledge covering many fields, there is less of a need to acquire or to develop additional different technologies in order to have a more diversified product portfolio.

As to hypothesis 2, we find that the technological coherence (TechCoh5(t-1)) of a firm's knowledge base, shows no significant influence on future product diversity. Hence, firms with technologies already related in the past as well as firms trying to combine as yet unrelated technologies may show the same degree of products-in-development diversity. Interpreting the former case as more incremental change and the latter case as more radical change, both types of invention strategies feed product diversity.

4.2 Variety design

To perform estimations in the variety design, we use ProdVar as the dependent variable and TechVar as our main explanatory variable. The dependent variable is a count variable, which is overdispersed (see Table 4), so we use instead the negative binomial regression as our basic estimation method.

Table 4: Descriptive statistics for variety estimation

Variable	Observations	Mean	Std. Dev.	Min	Max
ProdVar(t)	127	10.45669	12.76513	1	75
TechVar5(t-1)	127	5.055118	4.069451	1	18
TechBreadth5(t-1)	127	0.4442902	0.3652454	0.0196721	1
TechCoh5(t-1)	127	0.4485165	0.7131732	-1.085976	3.648247
ProdCoh(t)	127	3.030948	2.921192	0	26.59358
ProdCohSub(t)	127	0.5800857	0.3852686	0	1.224365
AppProdVar5(t-1)	127	5.582677	4.401372	0	15
ProdVar5(t-1)	127	22.27559	23.79765	0	95
Sales(t-1)	127	525.7014	767.4612	0.0260153	3983.009

Variables description can be found in the Appendix.

As in our previous estimations for the diversity design, we are concerned about our data as having a clustered structure. In other words, we suspect that unobserved firm effects may have a significant impact on our estimation. The data indeed changes its structure when corrected for firm unobservable fixed effects, as can be seen in Table 5.¹ According to the Hausman test, fixed effects estimation is preferred to random effects. Thus negative binomial model accounting for fixed effects will be employed in the estimation.

¹Correlation tables of original and corrected for fixed effect variables can be found in the Appendix.

Table 5: Descriptive statistics for variety estimation, corrected for firm fixed effects

Variable	Observations	Mean	Std. Dev.	Min	Max
ProdVar(t)	127	10.45669	7.72669	-9.209974	60.79003
TechVar5(t-1)	127	5.055118	1.555963	0.7823908	9.388451
TechBreadth5(t-1)	127	0.4442902	0.1400183	0.0692902	0.8331791
TechCoh5(t-1)	127	0.4485165	0.2356335	-0.42909	1.814213
ProdCoh(t)	127	3.030948	2.640022	-2.961293	23.63229
ProdCohSub(t)	127	0.5800857	0.286763	-0.1164535	1.248425
AppProdVar5(t-1)	127	5.582677	1.011803	2.582677	8.582677
ProdVar5(t-1)	127	22.27559	13.28636	-26.22441	64.45741
Sales(t-1)	127	525.7014	321.4485	-470.9618	3497.138

Variables description can be found in the Appendix.

The fixed effects negative binomial estimation results are reported in Table 6. Models 1-4 differ in the way we control for changes in variables over time. Model 1 assumes no time effect. Model 2 and 3 account for structural changes in years 1998 and 2002, respectively, by including dummy variables $y98$ and $y02$. In model 4, dummy variables for years 1986-2007 are included.

The resulting coefficients on the control variables look quite similar to the ones obtained for the diversity design. Path-dependency again does not show up significantly. Product relatedness variables with respect to niches ($ProdCoh(t)$) and with respect to submarkets ($ProdCohSub(t)$) have significantly positive coefficients. Again, for $Sales(t-1)$ we obtain a positively significant coefficient. This confirms the notion that market similarities and firm size positively affect developing products' variety.

According to the estimation results for our core variables, hypothesis 1b cannot be rejected in all four models. The coefficient on technological variety ($TechVar5(t-1)$) is positive and significant - the variety of technological knowledge in the past leads to higher product variety. The interaction term between technological variety and technological breadth (Interaction) shows up as significantly negative in models 1-4. Hence, as in the diversity design estimation, we conclude that the technological variety effect on product variety diminishes with higher technological breadth. Technological breadth ($TechBreadth5(t-1)$), however, does not show a significant effect on product variety. Hence, hypothesis 1a is only partly confirmed. With respect to hypothesis 2, the coefficient on technological relatedness ($TechCoh5(t-1)$) is not significant. Thus, we conclude that there is no specific impact of technological relatedness ($TechCoh5(t-1)$) on future product variety. The interpretation we suggested for the similar result within the diver-

Table 6: Negative binomial estimation results. Dependent variable: Product variety

	1	2	3	4
	fe	fe	fe	fe
		y98	y02	year dummy
TechVar5(t-1)	0.0945*** (0.0343)	0.0943*** (0.034)	0.0798** (0.0346)	0.106*** (0.0347)
TechBreadth5(t-1)	0.297 (0.336)	0.292 (0.335)	0.474 (0.326)	0.334 (0.317)
Interaction	-0.357*** (0.101)	-0.350*** (0.101)	-0.264*** (0.0967)	-0.300*** (0.0946)
TechCoh5(t-1)	0.137 (0.16)	0.138 (0.16)	0.108 (0.144)	0.0638 (0.121)
ProdCoh(t)	0.0498** (0.0205)	0.0476** (0.0206)	0.0381* (0.0207)	0.0355* (0.0203)
ProdCohSub(t)	1.052*** (0.19)	1.002*** (0.195)	0.881*** (0.193)	0.897*** (0.191)
AppProdVar5(t-1)	-0.0293 (0.0371)	-0.032 (0.0371)	-0.0426 (0.037)	-0.00743 (0.0392)
ProdVar5(t-1)	0.00294 (0.00317)	0.00283 (0.00317)	-0.00111 (0.00321)	7.64E-05 (0.00471)
Sales(t-1)	0.000320** (0.000141)	0.000321** (0.000141)	0.000312** (0.000135)	0.000247* (0.000137)
y98		0.749 (0.733)		
y02			0.691*** (0.188)	
Constant	1.727*** (0.54)	1.051 (0.872)	1.747*** (0.638)	3.195* (1.662)
Observations	127	127	127	127
Number of firm	25	25	25	25
R-squared

Robust standard errors in parenthesis.

* significant at 10%; ** significant at 5%; *** significant at 1%.

sity design applies equally here.

Our estimations, both within the diversity and the variety design, deliver quite similar results, regardless of whether the diversity is measured according to the "effective diversity" concept (diversity design) or along the more simple measure of diversity (variety design). The comparison between diversity and variety estimation and the obtained qualitatively equivalent results can be taken as a robustness check of our analysis.

5 Conclusion

This paper deals with the R&D strategies of firms and focuses on product development. The question addressed asks for the relationship between the diversity of a firm's products-in-development portfolio and the determinants driving it. Here we distinguish between market and technology related factors. The former refer to similarities among the products in a firm's portfolio. The latter factors take into account a firm's technological knowledge base. This can be characterized by its diversity, the relatedness of the knowledge components, and its breadth. The presumed relationships are tested on the basis of the data on large pharmaceutical and biotech firms engaged in product development. The database comprises information on those development projects, as well as on the technological knowledge involved in the projects.

Our empirical analysis finds that the diversity of a firm's product portfolio is positively dependent of the diversity of that firm's past technological knowledge base. This positive effect is reduced when the breadth of a firm's knowledge base is taken into account and interacts with the measure of technological diversity. The coherence of a firm's technological knowledge components shows no significant effect on portfolio diversity. These results have been obtained by simultaneously controlling for firm size and product portfolio structures, both showing a positively significant effect on a firms' products-in-development diversity.

The results of our analysis shed light on the research strategies of established firms, in this case from the pharmaceutical and biotech sectors. These firms tend to diversify their product portfolio in accordance with their research experience and prior market orientations. We obtained these results by studying the firms with respect to the technological and product sets they possess. This portfolio-based approach has the advantage of assessing diversification in a more comprehensive way. It obviously has the disadvantage of not covering certain interesting aspects of diversification, such as competition, spillovers, technological leads, and lags, as well as the direction and intensity of particular research projects. Take as an example our result on technological coherence as

showing no significant effect on products-in-development diversity. Here it remains open whether the development projects are of a more incremental or more radical type. Only a project based approach will be able to deliver results on these determinants. This line of further investigation will be the next step of our research.

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6 Appendix

Table 7: Variables Description

Variable	Label	Description
Product Diversity	ProdDiv	Disparity and evenness of a product portfolio
Technological Diversity	TechDiv	Disparity and evenness of technological portfolio, measured in IPC
Technological Breadth	TechBreadth	Number of different technological fields weighted by total number of technologies
Technological Coherence	TechCoh	Distance between technologies in one firm portfolio in terms of IPC
Product Coherence Niche	ProdCoh	Distance between products in one firm portfolio in terms of niches
Product Coherence Submarket	ProdCohSub	Distance between products in one firm portfolio in terms of submarkets
Approved Product Diversity	AppProdDiv	Disparity and evenness of approved product portfolio

Table 8: Correlation table: Diversity design

	ProdDiv	TechDiv5(t-1)	TechBreadth5(t-1)	TechCph5(t-1)	ProdCoh (t)	ProdCohSub(t)	AppProdDiv5(t-1)	ProdDiv5(t-1)	Sales(t-1)
ProdDiv(t)	1								
TechDiv5(t-1)	0.0438 (0.2383)	1							
TechBreadth5(t-1)	-0.1233 (0.0009)	-0.3497 (0)	1						
TechCoh5(t-1)	0.0176 (0.6363)	-0.0257 (0.1679)	0.1231 (0)	1					
ProdCoh(t)	0.4672 (0)	0.0267 (0.4721)	-0.0184 (0.6196)	-0.005 (0.8923)	1				
ProdCohSub(t)	0.5715 (0)	0.0318 (0.3909)	-0.0577 (0.1202)	0.0031 (0.9333)	0.4914 (0)	1			
AppProdDiv5(t-1)	0.373 (0)	0.1477 (0.0192)	-0.0826 (0.192)	-0.1211 (0.0553)	0.1181 (0.0002)	0.2773 (0)	1		
ProdDiv5(t-1)	0.6105 (0)	0.0404 (0.1689)	-0.0701 (0.0169)	0.012 (0.6843)	0.2285 (0)	0.3314 (0)	0.3185 (0)	1	
Sales(t-1)	0.6789 (0)	0.1088 (0.1806)	-0.2076 (0.01)	-0.0366 (0.653)	0.127 (0.128)	0.3425 (0)	0.4395 (0)	0.6136 (0)	1

Variables description can be found in the Appendix.

Table 9: Correlation table corrected for firm fixed effects: Diversity design

	ProdDiv	TechDiv5(t-1)	TechBreadth5(t-1)	TechCoh5(t-1)	ProdCoh(t)	ProdCohSub(t)	AppProdDiv5(t-1)	ProdDiv5(t-1)	Sales(t-1)
ProdDiv(t)	1								
TechDiv5(t-1)	0.1596 (0.0928)	1							
TechBreadth5(t-1)	-0.1613 (0.0892)	-0.1519 (0.1099)	1						
TechCoh5(t-1)	0.0812 (0.3949)	0.2222 (0.0185)	0.0509 (0.5942)	1					
ProdCoh(t)	0.1869 (0.0485)	0.2236 (0.0178)	-0.1315 (0.167)	-0.0274 (0.7741)	1				
ProdCohSub(t)	0.3629 (0.0001)	0.3011 (0.0013)	0.0594 (0.5337)	0.0787 (0.4092)	0.1043 (0.2736)	1			
AppProdDiv5(t-1)	0.0712 (0.456)	0.3267 (0.0004)	0.0551 (0.5642)	0.1593 (0.0934)	0.0945 (0.3219)	0.2901 (0.0019)	1		
ProdDiv5(t-1)	0.5379 (0)	0.3153 (0.0007)	-0.1802 (0.0573)	-0.0349 (0.7149)	0.1275 (0.1803)	0.2957 (0.0015)	0.1896 (0.0452)	1	
Sales(t-1)	0.4969 (0)	-0.1139 (0.2317)	0.0596 (0.5325)	-0.1665 (0.0793)	0.1117 (0.2409)	0.1352 (0.1553)	0.1785 (0.0597)	0.5129 (0)	1

Variables description can be found in the Appendix.

Table 10: Correlation table: Variety design

	ProdVar	TechVar5(t-1)	TechBreadth5(t-1)	TechCoh5(t-1)	ProdCoh(t)	ProdCohSub(t)	AppProdVar5(t-1)	ProdVar5(t-1)	Sales(t-1)
ProdVar(t)	1								
TechVar5(t-1)	0.2825 (0.0013)	1							
TechBreadth5(t-1)	-0.2105 (0.0175)	-0.6562 (0)	1						
TechCoh5(t-1)	0.3936 (0)	0.1215 (0.1737)	-0.2903 (0.0009)	1					
ProdCoh(t)	0.1733 (0.0513)	0.0729 (0.4156)	0.0157 (0.861)	-0.0255 (0.7764)	1				
ProdCohSub(t)	0.5011 (0)	0.2264 (0.0105)	-0.2275 (0.0101)	0.2261 (0.0106)	0.199 (0.0249)	1			
AppProdVar5(t-1)	0.5305 (0)	0.2459 (0.0053)	-0.1841 (0.0383)	0.3517 (0.0001)	0.1108 (0.2151)	0.4063 (0)	1		
ProdVar5(t-1)	0.8084 (0)	0.2268 (0.0104)	-0.1594 (0.0734)	0.3293 (0.0002)	0.1781 (0.0452)	0.5155 (0)	0.4513 (0)	1	
Sales(t-1)	0.6814 (0)	0.1465 (0.1003)	-0.1976 (0.026)	0.3679 (0)	0.0974 (0.2762)	0.3441 (0.0001)	0.3633 (0)	0.6227 (0)	1

Variables description can be found in the Appendix.

Table 11: Correlation table corrected for firm fixed effects: Variety design

	ProdVar	TechVar5(t-1)	TechBreadth5(t-1)	TechCoh5(t-1)	ProdCoh	ProdCohSub	AppProdVar5(t-1)	ProdVar5(t-1)	Sales(t-1)
ProdVar(t)	1								
TechVar5(t-1)	0.4102 (0)	1							
TechBreadth5(t-1)	-0.1396 (0.1176)	-0.2115 (0.017)	1						
TechCoh5(t-1)	0.0703 (0.4325)	0.2644 (0.0027)	0.0218 (0.8079)	1					
ProdCoh(t)	0.1384 (0.1208)	0.1832 (0.0392)	-0.1208 (0.1759)	-0.0076 (0.9325)	1				
ProdCohSub5(t-1)	0.2833 (0.0012)	0.3083 (0.0004)	-0.0172 (0.8481)	0.1046 (0.2418)	0.1642 (0.0651)	1			
AppProdVar5(t-1)	-0.0651 (0.4673)	0.1434 (0.1076)	0.1073 (0.23)	0.188 (0.0343)	0.0245 (0.7847)	0.2289 (0.0096)	1		
ProdVar5(t-1)	0.5787 (0)	0.5454 (0)	-0.1087 (0.2238)	-0.0524 (0.5586)	0.1172 (0.1895)	0.2358 (0.0076)	0.0348 (0.698)	1	
Sales(t-1)	0.2228 (0.0118)	0.0501 (0.5755)	0.0399 (0.6557)	-0.02 (0.8236)	0.0987 (0.2698)	0.163 (0.0671)	0.2689 (0.0022)	0.189 (0.0334)	1

Variables description can be found in the Appendix.