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Tatiana Plotnikova

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Friedrich Schiller University Jena
Carl-Zeiss-Str. 3
D-07743 Jena
www.uni-jena.de

Max Planck Institute of Economics
Kahlaische Str. 10
D-07745 Jena
www.econ.mpg.de

Technology, Competition and the Time of Entry: Diversification Patterns in the Development of New Drugs *

Tatiana Plotnikova†

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Abstract

This paper empirically investigates the determinants of R&D diversification strategies in the drug industry. It enriches the existing literature by proposing to look at diversification factors, which reflect market and technological proximity of an R&D project towards other projects within a firm's portfolio as well as R&D competition factors. Additionally, the characteristics of R&D in the market where a new potential product is developed affect future product choice. The analysis is performed for products-in-development data, merged with firms' patents, which allows us to separate project proximity in market niches from technological proximity. The results of empirical estimation support an idea that R&D diversification is governed by the economies of scope as well as the escape competition motive. Moreover, it is found that competition rather than spillovers in the niche where an R&D project is developed defines firms' decisions to diversify.

Keywords: diversification, technological diversity, relatedness, competition, R&D
JEL Classification: O32, L25, L65

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†DFG Research Training Program "The Economics of Innovative Change", Friedrich-Schiller-University Jena, Carl-Zeiss-Strasse 3, D-07743 Jena , Germany; e-mail: tatiana.plotnikova@gmail.com

1 Introduction

The issue of firm diversification[1] has been of interest to economists for several decades. Although most empirical diversification literature explores corporate or product diversification (Galan and Sanchez (2006); Lemelin (1982); Miller (2004); Montgomery (1994) among others) , technological diversification also gained research interest in some recent studies (e.g. Breschi et al. (2003); Gambardella and Torrisi (1998); Piscitello (2000)).

As regards the subject of the current paper, the determinants of R&D diversification have not been systematically studied, although R&D diversification was considered important in some research (Gino et al., 2006; Scott and Pascoe, 1987). As R&D strategies are recognized to be an important part of firm decisions, this topic needs some exploration.

An R&D project can be considered as standing in between technologies and markets as, from the one side, it comprises technological knowledge of a firm and, from the other side, it reflects this firm's perceptions of market competition. That is, when studying R&D project choice, one has to take into account both technological and market characteristics of a future product. This understanding of an R&D project allows us to connect different pieces of the theory of diversification in order to explain the R&D diversification choice.

In the current study, an R&D project is defined by both technological and market components. So, R&D diversification is explained first by firm internal determinants related to product and technological diversification. Specifically, market and technological relations of a new project to past firm activities affect whether this new project is developed in a previously known or different area. Firm external determinants of R&D diversification are related to the research activity in a market niche, where the new project is being developed. Competition, growth and research concentration are important factors of R&D diversification choices. We additionally claim that dynamic factors, such as the age of a certain field at the time of starting a new project, affect diversification decisions.

The empirical literature on technological diversification focuses mainly on the economies of scope in the utilization of firm's knowledge or technological base. Corporate diversification literature stresses similarities in the industries as determinants of the diversification decision. What is clearly missing is a competition motive of diversification. So, competition motives both internal, with R&D projects of the same firm, and external, on the level of market niche with other firms, are incorporated into an empirical model.

The main contribution of the current paper is to apply the theory of diversification

[1] Diversification here is firm expansion into areas where this firm was not represented before

to R&D projects of firms and to test it empirically. In doing so, we do not rely merely on the resource based view on firm, as do most of the studies in the field. We further enrich this approach by incorporating market competition among a firm's R&D projects as well as R&D competition in the market niche into which a firm diversifies.

The theoretical conclusions are tested on a data set, which originates from two sources: the European Patent Office and BioPharmInsight information about development drug projects. It is then possible to classify research projects as belonging to a certain market niche within the drug industry. At the same time, patent data by the European Patent Office allows us to classify firms' R&D portfolios within given technological fields.

The rest of the paper is organized as follows: a literature review in the Section 2 is followed by the data and variables description in Section 3. In Section 4, the empirical strategy and the results of our regressions are discussed. Section 5 concludes.

2 R&D diversification determinants

This section represents a review of the relevant literature on diversification determinants. First, we consider the most common motive to diversify: the economies of scope with respect to technological knowledge of a firm. Then, we turn to the demand side of the story, which is relevant because we believe that R&D projects are chosen with respect to both technology and market. Further, some insights from R&D competition and entry and exit literature help enrich more traditional diversification explanations of the economies of scope approach by claiming spillovers and competition as important in deciding whether or not to diversify.

2.1 Economies of scale

Empirical studies on corporate and technological diversification are usually concerned with economies of scope, which arise when a firm can use similar resources in the production and development of more than one product or technology. That is, they hint on a possible connection between the decision to diversify and the resources used, such as knowledge and experience.

This connection has been explored in the relevant literature. As a result, both product (Chatterjee and Wernerfelt (1991); Lemelin (1982); MacDonald (1985); Montgomery and Hariharan (1991); Silverman (1999)) and technological (Breschi et al., 2003) diversification studies find relatedness between markets and technologies, respectively, relevant when explaining diversification decision.

Other research, rather concerned with the theory of knowledge, also suggests that related and complementary resources are more productive (Nerkar and Roberts, 2004), while diversified and related resources are more likely to produce diversified knowledge (Breschi et al., 2003) which may be embedded in new products afterwards. Moreover, firms would diversify into those markets that are somehow related to their core, for example, in terms of distribution channels or production processes (Teece, 1982).

These empirical studies mostly test the diversification motive, which is reflected in the resource based view of the firm. According to Penrose (Penrose, 1959) and Teece (Teece, 1980), a firm expands by entering new markets when it can exploit economies of scope coming from the possession of a specific strategic resource. One of the examples of such a resource can be technology or knowledge. If a certain technology or knowledge can be used to produce different products, a firm owning this technology or knowledge need not bear the costs of acquiring this technology when entering some technologically related market (Wernerfelt, 1984).

Following Teece (Teece, 1980, 1982), firm expansion depends on the resources in this firm's possession. The direction of diversification is defined by the characteristics of strategic resources, mainly of the firm's knowledge. Strategic resources play an important role when a firm enters a new market (product diversification). If the relevant resource is technological knowledge, technological relations between already produced products and a new product will make it easier to handle the production and development of this new product. Applying similar logic to R&D projects, when deciding which new project to develop, a firm would choose the one which is technologically related to its previously developed projects. This conclusion is reflected in Proposition 1.

Proposition 1. To gain in scope economies, a firm will add a new project in a market which is technologically related to the projects it was developing before.

One extension of the argument above is that firms with a broader resource set can be expected to diversify more (Montgomery, 1994). If a firm is able to develop and to produce a product which it was not producing before, without substantially broadening its resource (knowledge) base, it would make the decision to diversify easier (given the market conditions). So, when the technological knowledge of a firm is broad, that is, it covers a broad set of technologies, it is easier for this firm to diversify as it is more probable that the technology needed to develop a new product is related to one or several technologies, which this firm already has. In other words, firms with a broader resource base (which includes technology and experience in product development) have more opportunities to diversify.

The breadth of knowledge approximated by a firm experience was addressed in some empirical work. In their study of corporate diversification, Montgomery and Hariharan

(1991) revealed that firms with broad resource bases, measured as past diversification, are more likely to diversify into different markets. With respect to R&D diversification, the intensity of R&D diversification has been addressed in Cantner and Plotnikova (2009). Using the data set similar to Gino et al. (2006) and the current study, that paper explains the diversity of a portfolio of new products-in-development by technological diversity. The effect of technological diversity has been found to be positive, but decreasing with the breadth of technological portfolio.

In the current paper, we attempt to test whether the knowledge breadth affects the decision to diversify. However, we will do it on a less aggregated level in comparison to the previous work, this being the level of a single project. The following proposition reflects our expectations of the relation between diversification and knowledge breadth.

Proposition 2. The cost of diversification for a firm with a broader knowledge portfolio is lower. So, this firm is expected to diversify more.

2.2 Demand side

Although very important and justified by empirical studies, scale economies are not the only determinant of R&D diversification. Another determinant is connected to the demand side of the story. The substitutability (or relatedness) between products is supposed to restrict diversification into technologically related markets. The degree of substitutability induces competition among products (Dixit and Stiglitz, 1977) and affects a firm's product portfolio choice (Shaked and Sutton, 1990). According to Ju (2003), multiproduct firms' proliferation behavior is influenced by the elasticity of substitution between products in one firm's portfolio. A higher elasticity of substitution leads to lower proliferation levels because of the competition effect. In other words, firms have no incentives to diversify into the markets of similar products, as the competition between these products is supposed to lower their total profits.

Empirical studies on diversification are mainly concerned with technological relatedness. However, market relatedness between the areas where a diversified firm is active has not yet been stressed, to the best of the author's knowledge. Although Miller (2004) mentioned the escape competition motive of diversification, it was not attributed to market relatedness between products.

We include market relatedness as one of the R&D diversification determinants. As the study is performed on the level of one industry, we prefer to operate with the concept of market niches rather than markets. The intuition concerning the impact of the market relatedness between projects in a firms' R&D portfolios on their choices to diversify is summarized in Proposition 3.

Proposition 3. To escape competition with itself, a firm will add a new project in a market which is rather far from the projects it was developing before.

To summarize the reasoning of the last two subsections, a firm is expected to diversify into R&D projects where it already has knowledge or technology (as in resource based view). Additionally, according to the demand perspective, these projects should not compete with each other when they become marketable. As R&D projects in the current study represent product development projects, it is expected that firms will select those R&D projects which are close in terms of firm technological and R&D knowledge and further away from other projects in firm's portfolio in terms of market relatedness. At the same time, broad knowledge and experience will allow them to capture more opportunities and by this favor diversification.

2.3 Spillovers vs competition

Technological and product market relatedness and knowledge breadth can be referred to as internal factors of diversification, as they reflect the relation between firm project portfolio elements. In addition, external factors, such as the situation in the market niche where a new project will be developed, should be relevant when making diversification decision. Generally speaking, more attractive market niches have to be chosen over less attractive.

The answer to the question as to which market niche is attractive for R&D diversification is ambiguous with respect to some factors. For example, the number of firms developing a future product in a certain area can signal both stronger competition and a higher possibility to learn, to imitate, or to collaborate. From the product competition point of view, the number of firms conducting R&D in a market niche reflects the severity of competition. The success of one firm in R&D affects the future gains from operating in this market niche for all other firms. That is, the higher number of firms tends to decrease incentives to start a project in a niche (following e.g. Loury (1979)).

The number of firms developing R&D projects in the same market niche can also represent spillover opportunities. The more peers work in the similar area, the higher should be an opportunity to gain from the research of others through collaboration or imitation of ideas and products. So, if spillover opportunities exist, the number of firms will positively affect the probability of a research success. This would make a market niche with intense R&D attractive to diversification.

As the effect of the number of competitiors/peers on diversification decision depends on whether competition or spillover effect is stronger in a given industry, we first concentrate on the significance of this effect in the Proposition 4. At the same time, we will be also interested in the sign of this effect as uncovering which effect has a higher impact of diversification decision in the drug development.

Proposition 4. The number of firms developing R&D projects in the market niche to entry affects incentives to diversify in R&D projects.

Following the logics of Scherer (1967), the allocation of more resources into development can decrease the development time. So, the research concentration may be desired to improve research success probability. That is, firms allocating more efforts in one niche can be expected to be potentially more successful. This implies that starting a project in a market niche with high research concentration (number of R&D projects by one firm) will signal lower success probability for an entrant firm. Then, it would create a negative incentive for a firm to start a project in a new (for this firm) niche with high research concentration. Bringing the spillovers argument again would result in the statement that more successful peers can affect a firm's research in a positive way if it is relatively easy to learn from them as well as form different types of collaborative agreements. As with the number of firms in development, it is not clear how research concentration affects R&D diversification behavior. So, Proposition 5 reflects a general expectation of the significance of research concentration for the decision to diversify. A positive (negative) effect of the former will signify that spillovers (competition) are more important for a firm in the development of new drugs.

Proposition 5. The research concentration in the market niche to entry affects incentives to diversify.

As opposed to the ambiguous conclusion on the effect of the number of firms and the niche research concentration on the decision to diversify in R&D, the growth of the market seems to have a rather straightforward impact on diversification. The growth in the market niche is supposed to signal increasing opportunities both in research and in future product market gains. So, firms may be attracted to diversification into growing niches.

Proposition 6. Firms start their R&D in growing market niches.

One more important factor, which may affect R&D diversification, is time. Specifically, the stage of industry evolution is expected to affect the decision to entry due to the changes in the innovation-imitation opportunities (e.g. Iwai (1984a,b)). It is easier to produce an incremental innovation in the early stages of market development, and so firms may prefer to enter at a certain period of time, rather close to the first entrant (e.g. Harris and Vickers (1985)). Similar conclusions on the timing of entry can be found in the literature on R&D competition (Grossman and Shapiro (1987); Harris and Vickers (1985); Reinganum (1985)) when analyzing incumbents-entrants behavior.

Proposition 7. Time of entry matters. The older the market, the harder it is to develop a new project. Hence, older markets attract fewer R&D projects.

3 Data and Variables

3.1 Methodological considerations

Existing research on diversification is mainly concentrated on unrelated, i.e. inter-industry, diversification and deals with conglomerates. Unrelated diversification as an expansion into different industries should mainly require some matching of organizational resources and practices in the primary and destination industry. As was found by Chatterjee and Wernerfelt (1991), unrelated (further related) market diversification is connected with financial resources availability, whereas intangible assets and physical resources favor related (closer related) diversification. So, conglomerate inter-industry diversification should be more connected to sharing more universal resources.

This consideration, coupled with an understanding that conglomerate organizations, which are usually the focus of interest in diversification studies, should not build their diversification strategies according to technological similarities among different products, makes it reasonable to investigate the diversification behavior inside one industry. It was also demonstrated by Bernard et al. (2006) that even firms participating in many industries concentrate their production/sales in one, major industry.

Related diversification and its determinants, such as the connection between firm resources and product markets, was not explored extensively. At the same time, the analysis of the related diversification patterns can be better attributed to the connection between technologies and products in one industry. This type of analysis has been done in the studies of technological diversity and relatedness and innovative productivity, which explored separate industries, such as pharmaceuticals and electronics (Nerkar and Roberts (2004); Breschi and Malerba (1999)). Restricting the analysis to one industry allows for clearer separation between diversifiers and specialists, both from a product and a technology perspective - as in this case, conglomerates are excluded.

The data set, which is described below, contains information on research projects of firms in one specific industry, the biopharmaceutical industry. This is better suited for questioning firm diversification and its connection to technological and product proximity.

3.2 Data structure

The data set employed in this study consists of two parts, from different sources. The part that accounts for R&D projects was acquired from the BioPharmInsight[2] web site, which provides publicly available information on new drug development projects worldwide. A project can be developed by a firm as well as by a university or a research institute. All drugs represented are in the clinical testing stage. This means that they are already defined as products, but need more testing to ensure their effects and safety. During the clinical trial period, which may last for several years, further development of a drug takes place.

The time span of the products-in-development data is from 1982 to 2007. The total number of products increases over time; so does the number of firms. In many cases, this data contains several observations per firm over time. It is also the case that many firms can have several projects in one year.

Each project belongs to one of 225 Indications. Each indication represents a condition (or disease, symptom) which makes a particular procedure or treatment advisable[3], that is, indications represent market niches in the medicine market. Each indication belongs to one of 13 therapeutic areas. An assignment to a therapeutic area is exclusive. As the therapeutic area is defined according to a system of an organism or a general disease group, indications in one therapeutic area are more related in terms of market demand than indications belonging to different therapeutic areas. For example, all medicines falling into the therapeutic area "Central nervous system" are considered to be close, whereas a medicine from this area would not be close to a medicine from the "Infectious diseases" therapeutic area.

There is also time when the information about this project has been announced. So, each project is characterized by the time of update, company, indication and therapeutic area.

The products-in-development data were matched according to a company name, with patent data acquired from European patent office. The time span of patent data is from 1978 to 2007. The total number of patents also increases over time. As with the project data, there are repeated observations for firms across time and patents. Each patent is classified according to International Patent Classification, which provides classification of patents according to the different areas of technology to which they belong. IPC4, that is, 4-digit classification, was chosen to represent one technology. The patent information included in the data is the time of application, company name (applicant), and IPC4 classification codes.

[2]http://www.infinata5.com/biopharm/
[3]This definition is from online medical dictionary: http://www.medterms.com

Each firm in the data set is represented by the set of products-in-development (or R&D projects), as well as the set of technologies at a given point of time. There is no more available information on other firm characteristics, such as financial information. However, for the sake of the current research question, that is, diversification direction, this information may not be relevant. Moreover, firm specific features can be controlled using proper econometric techniques.

3.3 Empirical model and variables

Diversification direction choice is usually explored with the help of the model proposed by Lemelin (Lemelin, 1982).

$$P(K, I, J) = f(W(K), X(I), Y(J), Z(I, J)) \tag{1}$$

P(K,I,J) is the probability of firm K with a principal activity in industry I to diversify in industry J; *W(K)* is the vector of characteristics of firm K; *X(I)* is the vector of characteristics of industry I; *Y(J)* is the vector of characteristics of industry J; *Z(I,J)* is the vector of variables describing the relationship between industries I and J.

As is noticeable from the model, a firm is characterized by it's main or principal activity, this is a quite typical assumption for diversification direction studies (i.e. Breschi et al. (2003); Lemelin (1982); MacDonald (1985)). Other activities are considered in relation to the main activity. By contrast, considering a firm as belonging to several activities would better define the firm's position towards other products, industries and technologies.

The current paper looks at a firm as participating in several different projects. So, there is no defined principal activity, that is, the model to be estimated is a reduced version of the Lemelin's model. Moreover, the question is rather whether and why a firm diversifies. So, instead of probability to diversify in some industry, the dependent variable becomes the probability that a project J of a firm K is different from a previous project portfolio.

$$P(K, D(J) = 1) = f(W(K), Y(J), Z(K, J)) \tag{2}$$

P(K,D(J)=1) is the probability that project J, which firm K develops, is different from projects this firm was developing before ; *W(K)* is the vector of characteristics of firm K; *Y(J)* is the vector characteristics of the niche, where project J belongs; *Z(K,J)* is the vector of variables describing relationships between firm K and project J.

The interpretation of such a model is that it reflects the probability of diversifying for every product of a firm. This probability depends on this firm's internal characteristics (breadth of knowledge), the characteristics of the niche where the project is reported (e.g. size, age, growth), and the relation between the firm and the project (relatedness to a past projects' portfolio technologically and in the product market sense).

3.3.1 Dependent variable

For each product-in-development, the question is whether a firm introducing this project had developed similar projects before. Similar projects would belong to one indication. If a firm did not produce a similar project before, the dependent variable takes the value of one, otherwise it is zero. The dependent variable is labeled $Different$.

3.3.2 Explanatory variables

Relatedness. The concept of relatedness, which is widely used in the literature on knowledge and technology (e.g. Teece et al. (1994); Piscitello (2000); Nesta (2008)), is applied when measuring technological distance between projects. This measure is modified in the current paper to capture technologically close products. Moreover, it is applied towards a single product to measure the distance between this product and previously developed bundle of products.

Following Teece et al. (1994), two projects are related if their joint appearance in firms' project portfolios is not random. However, in order to stress technological relatedness and also to escape a possible bias in estimations where some firm project portfolio variables will be present, the calculation of relatedness in this paper is modified. Instead of tracking the joint occurrence of different projects in firms portfolios, the measure is calculated based on the project appearance in IPC4 codes[4], which represent technology. Projects are related if they meet in one technology according to IPC4 classification more often than is predicted by the random pairwise co-occurrence, which follows hypergeometric distribution.

After calculating the technological relatedness index for each pair of projects [5] (a project is defined by an indication, so different projects belong to different indications), the technological relatedness of a firm project portfolio with respect to a new project is calculated. This is performed through weighting a firm's project portfolio by the pairwise technological relatedness index τ_{ij}. The weighted technological relatedness ($TechRel_{km}$) of a firm k's portfolio to a project m is the result of this calculation:

[4] To perform this measurement, indications were searched for in patent titles.
[5] Relatedness index calculation is presented in the Appendix, section 6.1

$$TechRel_{km} = \frac{\sum_j \tau_{mj} P_{kj}}{\sum_j P_{kj}} \tag{3}$$

where P_{kj} is the number of projects of type j in firm k's portfolio.

The classification of projects in the market is used to capture market relatedness (or substitutability). Each product is a drug treating a certain disease and is signified by an indication. Each indication belongs to a therapeutic area. So, the measure of relatedness of a new project towards a bundle of already developed projects is built according to the classification of indications into therapeutic areas. Each indication is considered to be close to another indication if both belong to the same therapeutic area. To measure the market relatedness between a new project and a bundle of firm's projects that were developed previously, the number of past projects belonging to the same therapeutic area as a new project is weighted by the total number of projects developed by this firm.

The market relatedness ($MktRel_{km}$) of firm k's portfolio to project m :

$$MktRel_{km} = \frac{\sum_j D_{mj} P_{kj}}{\sum_j P_{kj}} \tag{4}$$

where P_{kj} is the number of projects j in a firm k's portfolio, and D_{mj} is equal to one if projects m and j belong to a similar therapeutic area and zero otherwise.

The measures of technological and market relatedness in this study cannot perfectly distinguish between technological and product relations, because it is impossible to separate one from another. Especially it is true for the market of drugs, where a product strongly depends on technology. However, as the first measure incorporates patent information, it is expected to be more biased towards technological relatedness. At the same time, the second measure follows market classification, which provides an exclusive separation of products into different sub-markets (therapeutic areas). So, at least it can be claimed that these two measures capture different aspects of project relatedness.

Knowledge breadth. Knowledge breadth is approximated by the number of different technologies (technological knowledge diversity) or projects (project knowledge diversity) a firm acquired and developed over the last five years. Using stocks here is more intuitive than applying flow variables, as we try to capture knowledge breadth. The five year period was taken assuming 20% depreciation rate on knowledge (following Henderson and Cockburn (1996)). However, as experience is a qualitative variable, it is not possible to depreciate its value without directly asking each firm what knowledge is no longer used. So, the stock of technologies (or projects when measuring project development experience) is not depreciated before counting the number of different IPC4 technologies (or indications for project development experience) in it.

There are two separate measures for knowledge diversity: technological diversity ($DiversTech$), measured by the number of different IPC4 codes in a firm patent portfolio over the last five years; and project diversity ($DiversProj$),which is calculated as a number of different indications in a firm project portfolio over the last five years.

Number of competitors. Among niche characteristics that could affect the diversification decision, the number of firms as well as the number of projects in one niche can signal competition or attractiveness of this niche. As these two variables are strongly correlated, the number of firms is chosen to proxy the number of competitors. The number of niche participants is measured by a simple count of firms having research in this niche ($NumFirms$). The variable is one period lagged, as current market information is assumed to be not available to firms.

Growth. Growth is measured as a relative change in the niche participants' number ($Growth$) in the current period compared to the previous period. This is assumed to signify increasing gain opportunities.

Research concentration. The average number of research projects per firm ($Pconc$) is the measure for average research concentration in a niche. The variable $Pconc$ is one period lagged, as it is assumed that firms can assess only the past information about the market.

Niche age. Niche age ($Time$) may be important for the diversification decision. Entering into a well established niche can not be preferred by a non-incumbent firm, as it would have to catch up with other competitors. Niche age at the time of entry ($Time$) is the time lag between the time of the first entry (given the data) in a niche and a firm's entry into this niche.

4 Estimation

4.1 Sample description

As has been said before, the data set includes firms, research institutes and universities. In this section, some description of the data at hand is provided.

Table 1: Share of multi-project and one-project organizations.

	Multi-project	One-project	Total	Number of Observations
Share of Organizations	67.33227	32.66773	100	2504
Share of Projects	0.957302432	0.042697568	100	19158

Table 2: Share of multi-project and one-project firms.

	Multi-project	One-project	Total	Number of Observations
Share of Firms	67.56993007	32.43006993	100	2288
Share of Projects	95.54621849	4.453781513	100	16660

Most organizations in the sample have more than one project over the data time span (the matched data is from 1982 to 2007): around 67% of organizations in the data developed more than one project over 25 years of observations. Most projects are developed by organizations with more than one project (these organizations are called multi-project in Table 1): around 95% of all projects were developed by a multi-project organization, whereas only about 5% of 19158 projects in the sample were managed by a one-project organization.

Similar proportions hold for firms only (see Table 2). More than 67 % of firms are multi-project, developing more than 95% of all R&D projects in the given sample. Only 5% of projects by private firms are developed by one-project firms, which account for less than one third of all firms' population.

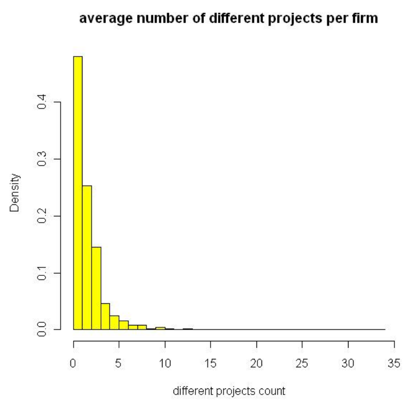

Figure 1: Average number of different projects per firm

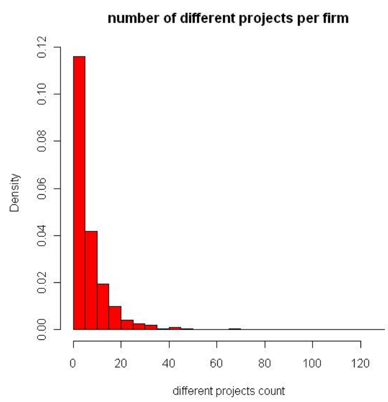

Figure 2: Total number of different projects per firm

Most multi-project firms are active in a small number of indications (niches). This can be seen from figures 1 and 2. Figure 2 plots the distribution of different projects per firm over the whole sample. This distribution is skewed towards a small average number of projects.

Figure 1 plots the distribution of the average number of different projects per firm over the entire sample. Average is calculated over time. The average number of different projects per year in one firm is also skewed. Most firms have fewer than five projects per year.

The number of firms choosing to develop a project in one or another niche differs

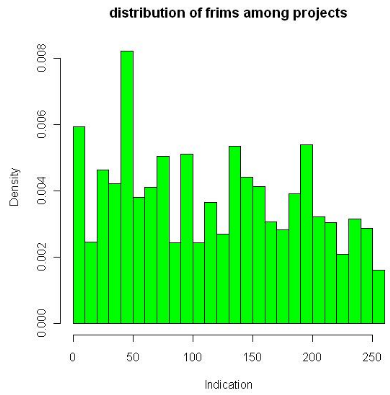

Figure 3: Distribution of firms among different indications

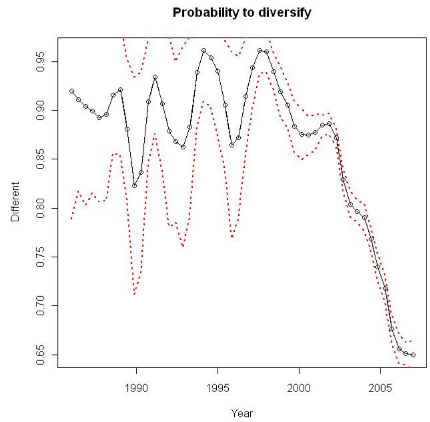

Figure 4: Estimated probability to diversify over time

among niches. Firms are not distributed evenly among project types or indications. This is demonstrated in Figure 3.

Out of all projects developed by multi-project firms, more than 75% were different from firms' past projects portfolios. This number varies over time. In the period of time after 2000-2002, the probability of diversification in R&D decreases. Figure 4 represents the estimated probability to diversify given the year of observation. Dotted lines show errors in probability prediction. Given that the number of observations increases from 658 in 2001 to 2958 in 2002, the accuracy of the average probability estimation is better in years 2002-2007.

Table 3: Descriptive statistics of standardized variables. Non-diverse projects.

Variable	Obs	Mean	Std. Dev.	Min	Max
MktRel(t)	4439	0.553548	1.065263	-0.62529	2.798875
TechRel(t)	4439	0.28706	1.223457	-0.28267	23.83033
NumFirms(t-1)	4439	0.26727	1.136838	-0.78322	5.23541
Growth(t)	4439	-0.21108	0.579015	-0.84038	8.383192
Time(t)	4439	0.165754	0.97317	-1.87922	1.832792
Pconc(t-1)	4439	0.159476	1.029727	-0.67344	10.1852
DiversProj(t-1)	4439	0.752225	1.348422	-0.55056	4.093565
DiversTech(t-1)	4439	0.223507	1.343087	-0.31762	6.907838

The descriptive statistics for the variables of interest are reported in Table 6 in the Appendix, and Tables 3 and 4. Table 6 represents descriptive statistics of variables for the whole sample. Table 3 and table 4 report statistics for the sample of non-diverse and diverse projects. All explanatory variables in these tables and in further estimation are standardized, that is, they all have means of zero (see table 6 in the Appendix).

It is noticeable that there are differences in the levels of means and standard deviations

Table 4: Descriptive statistics of standardized variables. Diverse projects.

Variable	Obs	Mean	Std. Dev.	Min	Max
MktRel(t)	13626	-0.18033	0.907645	-0.63835	2.798875
TechRel(t)	13626	-0.09352	0.895905	-0.41338	27.48367
NumFirms(t-1)	13626	-0.08707	0.934867	-0.78322	5.23541
Growth(t)	13626	0.068766	1.094235	-0.83559	11.60139
Time(t)	13626	-0.054	1.002721	-1.87922	1.832792
Pconc(t-1)	13626	-0.05195	0.984599	-0.67344	10.1852
DiversProj(t-1)	13626	-0.24506	0.699389	-0.59565	4.093565
DiversTech(t-1)	13626	-0.07281	0.846553	-0.31762	6.907838

between the sample of diverse and non-diverse projects. Diverse projects are those that were not developed five years before. For these projects, all variables except for $Growth(t)$ have a mean below the overall sample mean (Table 4). By contrast, projects similar to previous portfolio (non-diverse projects) are characterized by above-mean values for market and technological relatedness ($MktRel(t)$ and $TechRel(t)$) and other variables except for the mean of $Growth(t)$, which is below the mean (Table 3).

4.2 Estimation method

The dependent variable is a binary variable, so methods applicable for limited dependent variables must be used. Logistic estimation was chosen following the literature (e.g. Breschi et al. (2003); Merino and Rodrguez (1997); Montgomery (1994)) and also due to less strict assumptions implied by the logistic panel data estimation. Specifically, fixed effects logit does not make any assumption about the distribution of unobserved fixed effects (Wooldridge, 2002).

As is claimed by Merino and Rodrguez (1997), there is always some information about a firm which is not possible to control for. Specifically, the diversification decision analysis will only be consistent in the presence of fixed effects estimation. In the case of the data at hand, this estimation technique seems to be the most appropriate also due to the absence of precise size and R&D expenditures information. Even though the R&D expenditures, which are expected to be correlated with size, will be controlled for by using the total number of research projects ($logTotalProj(t)$), other firm information, which may be relevant for diversification direction choice, is not available.

From the statistical point of view, within and between unit (i.e. firm) correlation for variables were compared for all sample. The correlation within observations belonging to one firm was found to be higher than between units correlation for all variables, except for technological diversity ($DiversTech(t-1)$)(Table 8 in Appendix). Moreover, the Hausman test (Hausman, 1978) was performed on the regression over the entire sample.

The results suggested that there have to be a unit heterogeneity in the sample, which is better captured by fixed-effects rather than random-effects specification.

Firms with large project portfolios are assumed to have higher R&D expenditures. Given that firm size may play an important role in diversification behavior, the logarithm of total number of projects in a firm over five years was included as a control variable ($logTotalProj(t)$). Introducing this variable as a proxy for R&D expenditures is consistent with Henderson and Cockburn (1996), who found that economies of scale in drug discovery are relevant on the level of the entire research effort.

The relation between the dependent variable and some explanatory variables is expected to be captured by a more complicated than linear functional form. In order to capture non-linearities in the effect of past project diversity ($DiversProj(t-1)$), past technological diversity ($DiversTech(t-1)$) and niche age ($Time(t)$), the logarithms of these variables were included into regressions.

To take into account the time structure of the data, a variable that equals to one for the years later or equal to 2002 and zero otherwise ($y02$) was created and put into regressions. This variable is preferred to the inclusion of dummy variables for each year because the high number of dummy variables causes complications in the fixed-effects logit estimation.

Seven models will be estimated in the next section. The first model includes only relatedness and diversity measures, together with controls. Models 2-4 add industry specific variables: the number of firms ($NumFirms(t-1)$), research concentration ($Pconc(t-1)$) and niche age ($logTime(t)$). All variables mentioned before comprise Model 5. Model 6 restricts the sample to firms as distinct from universities and research institutes. Model 7 is estimated only for universities and research institutes.

4.3 Results

Estimation results are reported in Table 5. Explanatory variables were standardized before running regressions.

Model 1 estimates the fixed effects logistic regression on two relatedness measures, logarithms of past project and technological diversity, and two control variables. Both technological and market relatedness between a new project and past portfolio of projects are significant. Market relatedness of a new project is negatively connected to the probability that a firm diversifies. This result is in line with the Proposition 3, that is, that a firm would not start a new different project in a closely related market niche.

Technological relatedness coefficient is positively significant, supporting our Proposition 1. So, firm diversification probability is higher if a new project belongs to a technologically close niche. As was expected, firms diversify into technologically close

Table 5: Fixed effects logit estimation results. Dependent variable: Different. Coefficients on standardized variables are reported.

	1	2	3	4	5	6	7
		NumFirm	Pconc	Time	whole sample	only firms	only uni
MktRel(t)	**-1.171******	**-1.171******	**-1.224******	**-1.167******	**-1.194******	**-1.182******	**-1.410******
	(0.037)	(0.038)	(0.0393)	(0.0373)	(0.0396)	(0.0408)	(0.171)
TechRel(t)	**0.0747******	**0.0728******	**0.0591*****	**0.0733******	**0.0668******	**0.0773******	**-0.0939**
	(0.0252)	(0.0256)	(0.0253)	(0.0254)	(0.0259)	(0.0271)	(0.1)
logDiversTech(t-1)	**0.0927**	**0.0878**	**0.12**	**0.106**	**0.122**	**0.123**	**-6.507**
	(0.0802)	(0.0824)	(0.0846)	(0.0805)	(0.0861)	(0.0863)	(292)
logDiversProj(t-1)	**-2.889******	**-2.706******	**-2.747******	**-2.765******	**-2.578******	**-2.627******	**-2.338******
	(0.104)	(0.106)	(0.107)	(0.104)	(0.112)	(0.12)	(0.3)
NumFirms(t-1)		**-0.636******			**-0.525******	**-0.523******	**-0.605******
		(0.0291)			(0.0368)	(0.039)	(0.122)
Pconc(t-1)			**-0.429******		**-0.0888******	**-0.0557**	**-0.367******
			(0.0288)		(0.0344)	(0.0367)	(0.102)
logTime(t)				**-0.301******	**-0.0724*****	**-0.05**	**-0.218*****
				(0.0283)	(0.0318)	(0.0341)	(0.0906)
Growth(t)					**0.0702***	**0.0582**	**0.166**
					(0.037)	(0.0387)	(0.121)
logTotalProj(t)	**0.603******	**0.448******	**0.573******	**0.627******	**0.451******	**0.477******	**0.473**
	(0.115)	(0.119)	(0.12)	(0.115)	(0.123)	(0.134)	(0.327)
y02	**0.400******	**0.781******	**0.657******	**0.450******	**0.838******	**0.843******	**0.657**
	(0.131)	(0.136)	(0.14)	(0.133)	(0.144)	(0.152)	(0.459)
Observations	14489	14489	13580	14489	13580	11936	1644
Number of units	776	776	770	776	770	733	37
ROC area	0.8625	0.8741	0.8586	0.8656	0.8646	0.858	0.8945
	p = 0.0000	p = 0.0000	p = 0.0000	p = 0.0000	p = 0.0000	p = 0.0000	p = 0.0000
Brier score †	0.5775	0.5796	0.5625	0.5787	0.5638	0.5562	0.6143
Log likelihood	-5185.9456	-4904.1528	-4851.3024	-5127.0963	-4711.5198	-4118.3508	-580.35891
McFadden's R square	0.2760	0.3153	0.3227	0.2842	0.2456	0.4250	0.3670

*** $p<0.01$, ** $p<0.05$, * $p<0.1$ Standard errors in parentheses
† Sanders-modified Brier score

areas.

Both technological and market relatedness coefficients are significant and have the expected signs in all models but the last one (Model 7). The last regression was performed on the sample of universities and research institutes. It seems logical to assume that these organizations have different research strategies as compared to firms. Although they care about the spread of their research to cover more various indications (coefficient on market relatedness in Model 7 is positively significant), the economies of scope do not seem to play a role for universities and research institutes (technological relatedness coefficient is insignificant in Model 7).

Knowledge breadth, which is measured by the diversity of technological ($logDiversTech(t-1)$) and project ($logDiversProj(t-1)$) portfolio over the last five years, does not behave as was expected [6]. Technological diversity is not significant. Project diversity has a negative coefficient, which is significant in all models. This means that the more projects a firm was developing over the last five years, the lower is the probability that its new

[6] To remind, in Proposition 2 it was stated that knowledge breadth was expected to affect diversification positively

project will be diverse. One explanation of this sign is that firms with a higher number of different projects in the past have no opportunity to diversify, due to a restricted number of areas in which they can diversify (225 indications). Indeed, the number of areas to diversify has to decrease the more areas are already explored by a firm. This decreases the probability to diversify. Additionally, the probability to diversify may decrease with broader knowledge due to restricted capabilities of an organization to manage a diverse project portfolio.

Variables characterizing the niche to entry, that is, the number of firms ($NumFirms(t-1)$), research concentration ($Pconc(t-1)$) and niche age ($logTime(t)$), show negative significant coefficients when included separately. The number of firms in the niche negatively affects the probability of entry. This finding suggests that competition rather than research spillovers define the firm decision on R&D diversification. Project concentration affects diversification decision negatively, which is also in line with the prevailing competition effect. Niche age was connected to the development of research in the niche. So, the negative sign on this variable can be interpreted as a low expectation of success for late entrants and, as a consequence, a lower probability of entry. As the sign on the variable ($logTime(t)$) is negative and its coefficient is significant on 1%, Proposition 7 cannot be rejected.

All these variables reflect the expectation about R&D competition in a different way. They are also correlated (look at the Table 7 in Section 6.2 of the Appendix). However they are all significant in Model 5, which includes each of them. Note that the signs of coefficients in Model 5 remain consistent with our previous findings.

Model 5 also includes a growth variable ($Growth(t)$), which proved to be positive and significant in the presence of all other variables. However, it loses its significance for the sample of firms (Model 6) and the sample of universities and research institutes (Model 7).

In Model 6, which was estimated for the sample of firms, among variables describing a niche, only the coefficient on the number of firms ($NumFirms(t-1)$) was significant. On the other hand, all three variables characterizing the niche situation one period before decision to diversify are significantly negative in institutes and universities sample. This observation may be interpreted as suggesting that firms probably account on the number of future competitors, whereas research institutes and universities develop medicines in new areas, often being the first or one of the first entrants into these niches.

It is also noticeable that the proxy for the size of R&D ($logTotalProj(t)$) is not significant for the institutes and universities sample. The argument, similar to the one brought before, that purposes of these organizations differ from firm aims, can explain the difference with respect to the firm sample. Specifically, it is believed that research institutes and universities perform basic and more risky research.

Generally speaking, the regression results are in line with our expectations, which were built upon theoretical considerations. The escape competition and the economies of scope motive have been confirmed as defining diversification decision for the current sample of firms. Moreover, the previously acquired knowledge affects the probability of diversification. Although the effect of the diversity of firm knowledge on the probability to diversify was significantly negative, contrary to expectations, it can be explained by the decreasing number of the possible fields to diversify when diversification before was extensive. Competition in the niche to entry reduces incentives to diversify. So does the research concentration and niche age.

One should note that the goodness of fit of presented regressions is rather modest, which is quite common for this type of study (i.e. Montgomery (1994)). Brier score, which represents the mean squared error of the forecast, is quite big (more than 0.5 for all models). McFadden's R-squared is in the range from almost 0.25 to more than 0.42. The best fitted model according to these two criteria is Model 6, which includes all explanatory variables and restricts the sample solely to firms.

5 Conclusion

This study explains R&D diversification by firms in the drug industry. We move away from the traditional view of a firm as belonging to one industry and consider it as being defined by its technological and R&D portfolios. This view allows us to stress interrelations between the R&D projects of one firm as being defined by technological or market proximity. As a result, it has been shown that R&D diversification is performed further away from other firm's projects in terms of product market proximity and closer in terms of technological proximity. Both technological and R&D projects were defined in the framework of one industry, where R&D is devoted to drug development projects.

Extending the possible determinants of diversification to the external environment brought us to the conclusion that R&D diversification is also affected by R&D competition. As has been demonstrated in the empirical part of the study, firms do not diversify into the niches with many participants and high research concentration. They prefer to diversify in the relatively young market niches due to the higher probability of successful project accomplishment. Moreover, the growth in the number of niche participants induces firms to diversify.

Sample division into research institutes and universities and firms showed that there are significant differences in the determinants of diversification decision for these two groups. Research institutes and universities are not restricted by technological relatedness and seem to be more concerned with the time of entry. Firms' diversification decisions are affected by market and technological relatedness and the number of competitors in the niche to entry. Although it is known that many projects in research institutes and universities are supported by firms, the difference in the regression results between these two groups demonstrates the disagreement of strategic objectives between them.

Our findings are useful for the understanding of diversification behavior. As can be concluded from the paper, diversification decisions are based both on economies of scope and competition motives. So, R&D diversification is a strategic choice, which aims at higher expected returns through economizing on resources (knowledge and experience) and escaping competition.

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6 Appendix

6.1 Relatedness calculation

To calculate relatedness, the actual number of pairwise co-occurrences of projects in a technology is compared with a random number generated from the hypergeometric distribution with mean μ_{ij} and variance σ^2_{ij}.

In equation (5) μ_{ij} is expected number of technologies where both projects i and j jointly appear.

$$\mu_{ij} = E(X_{ij} = x) = \frac{n_i \cdot n_j}{K} \tag{5}$$

K is population size (number of technologies), n_i is the number of projects of type i and n_j is the number of projects of type j.

$$\sigma^2_{ij} = \mu_{ij}\left(\frac{K - n_i}{K}\right) \cdot \left(\frac{K - n_j}{K - 1}\right) \tag{6}$$

σ^2_{ij} is the variance of the hypergeometric distribution with parameters K, n_i and n_j.

Relatedness of two projects is calculated as τ_{ij}:

$$\tau_{ij} = \frac{J_{ij} - \mu_{ij}}{\sigma^2_{ij}} \tag{7}$$

where J_{ij} is actual number of joint occurrences of projects i and j in one technology.

6.2 Tables

Table 6: Descriptive statistics of standardized variables

Variable	Obs	Mean	Std. Dev.	Min	Max
MktRel(t)	18065	0.00	1	-0.63835	2.798875
TechRel(t)	18065	0.00	1	-0.41338	27.48367
NumFirms(t-1)	18065	0.00	1	-0.78322	5.23541
Growth(t)	18065	0.00	1	-0.84038	11.60139
Time(t)	18065	0.00	1	-1.87922	1.832792
Pconc(t-1)	18065	0.00	1	-0.67344	10.1852
DiversProj(t-1)	18065	0.00	1	-0.59565	4.093565
DiversTech(t-1)	18065	0.00	1	-0.31762	6.907838

Table 7: Correlation table. Standardized variables.

		1	2	3	4	5	6	7	8
1	Different	1							
2	MktRel(t)	-0.316	1						
		(0)							
3	TechRel(t)	-0.1638	-0.0191	1					
		(0)	(0.0101)						
4	NumFirms(t-1)	-0.1526	0.0778	-0.0213	1				
		(0)	(0)	(0.0042)					
5	Growth(t)	0.1205	-0.0453	-0.0411	-0.2659	1			
		(0)	(0)	(0)	(0)				
6	Time(t)	-0.0946	0.0842	0.0166	0.3511	-0.1055	1		
		(0)	(0)	(0.0254)	(0)	(0)			
7	Pconc(t-1)	-0.091	-0.0125	-0.0238	0.6076	-0.1967	0.2365	1	
		(0)	(0.0922)	(0.0014)	(0)	(0)	(0)		
8	DiversProj(t-1)	-0.4294	-0.0471	0.3674	-0.0207	-0.0874	0.0328	-0.0027	1
		(0)	(0)	(0)	(0.0054)	(0)	(0)	(0.712)	
9	DiversTech(t-1)	-0.1276	-0.0007	0.2043	-0.0241	-0.0036	0.017	-0.021	0.2722
		(0)	(0.9301)	(0)	(0.0012)	(0.632)	(0.022)	(0.0047)	(0)

significance levels in parenthesis

Table 8: Within and between variation. Standardized variables. Group variable: Firm.

Variable		Mean	Std. Dev.	Min	Max
MktRel(t)	overall	0.00	1	-0.63835	2.798875
	between		0.703223	-0.63835	2.798875
	within		0.741712	-3.26537	3.151433
TechRel(t)	overall	0.00	1	-0.41338	27.48367
	between		0.281614	-0.28101	6.233005
	within		0.732351	-6.51343	22.30092
NumFirms(t-1)	overall	0.00	1	-0.78322	5.23541
	between		0.801704	-0.78322	5.23541
	within		0.88415	-3.25382	5.467886
Growth(t)	overall	0.00	1	-0.84038	11.60139
	between		0.671941	-0.78866	11.60139
	within		0.896597	-5.95031	11.57719
Time(t)	overall	0.00	1	-1.87922	1.832792
	between		0.741394	-1.87922	1.832792
	within		0.894767	-2.43702	2.32225
Pconc(t-1)	overall	0.00	1	-0.67344	10.1852
	between		0.825065	-0.67344	10.1852
	within		0.886255	-5.42932	10.34234
DiversProj(t-1)	overall	0.00	1	-0.59565	4.093565
	between		0.222667	-0.59565	2.474933
	within		0.531471	-3.07058	1.949852
DiversTech(t-1)	overall	0.00	1	-0.31762	6.907838
	between		0.619492	-0.31762	6.506423
	within		0.256367	-3.80006	2.8099