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Performance effects of knowledge diversity and knowledge relatedness in different phases of the innovation process

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Abstract

This paper is about the extent and the nature of the range of firms? innovative activities and the role of knowledge-relatedness in affecting firm?s innovation success in different phases of the innovation process. Focusing on the diversity and the coherence of the firm?s knowledge base, the dynamics and effects on innovative performance in different phases of the innovation process are evaluated.

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1. Introduction

This paper is about the extent and the nature of the range of firms' innovative activities and the role of knowledge-relatedness in affecting firm's innovation success in different phases of the innovation process. Focusing on the diversity and the coherence of the firm's knowledge base, the dynamics and effects on innovative performance in different phases of the innovation process are evaluated.

Most firms span their innovation activities over more than one innovation field, i.e. they are diversified in terms of innovation activities. Such diversity can be defined as the diversity in the knowledge system and principles underlying the nature of new products and their methods of production. It's located at the input level of the firm and does not necessarily have to be associated with product diversification (Granstrand et al., 1997; Gambardella and Torrisi, 1998)

For developing product innovation, firms use various scientific and knowledge sources, embodying different characteristics and dynamics (Dosi, 1988). The range of knowledge relevant to firms' innovation processes is expanding in both breadth and depth (Wang and von Tunzelmann, 2000). During product development process, a firm's capacity for action resides in its competencies. Competencies and knowledge are closely linked. The ability to generate and transfer knowledge is one of the key competencies necessary for gaining competitive advantage (Kogut/Zander, 1993; Grant 1996). Competencies themselves are a function of firms knowledge base. Cockburn and Henderson (1994) differentiate two fundamental types of competencies necessary for successfully performing new product development: local competence and architectural competence. Local competence is embedded in individual knowledge base of employees or in the collective knowledge base of a group within the firm. Local competence comprises all sources of firm specific expertise and knowledge in a particular R&D domain, e.g. distinct technology fields or different areas of basic or applied research.

In contrast, architectural competence is assigned to a subordinate knowledge level of the firm and independent from specific R&D domains. Architectural competencies are used to exploit existing component competencies via combination and integration activities. They are also necessary to make use of current component competencies for exploring new component competences to ensure

competitive advantage in the future. Sophisticated architectural competencies allow for integrating knowledge flexibility within and across R&D domains. They also ensure a critical degree of absorptive capacity for the identification, access and integration of new knowledge from outside the boundaries of the organization (Cohen/Levinthal, 1990; Lane/Lubatkin, 1998). Furthermore, they enable firms to conduct knowledge production and knowledge application processes simultaneously and therefore a necessary prerequisite for knowledge diversification.

Despite the increasing awareness of the economic relevance of knowledge, only little work is done on the interrelationship between the knowledge base on the innovation success of the firm. Existing literature investigates knowledge dynamics on the aggregated level of whole organizations (e.g. Garcia-Vega, 2006; Leten et al., 2007; Piscitello, 2000, 2004; Breschi et al., 2003; Nesta/Saviotti, 2005). The implicit assumption of global knowledge effects on innovation performance is made. There is no differentiation between the specific role and effects of knowledge according to different knowledge processes and knowledge dimensions. The focus is on overall economic growth of the firm, neglecting the fact that the requirements and the characteristics of the knowledge base differs substantially in different knowledge processes, sub-processes and tasks conducted in the firm (Knight, 1967).In this paper we address this research gap. For our research purpose we combine two different research areas into an integrative approach. First we built on the theoretical basis of the knowledge based view (Grant, 1996; Spender, 1996; Al-Laham, 2004). Taking further into account a new product development (NPD) perspective enables us to analyze the performance impacts of the firm's knowledge base from a dynamic process perspective. On the disaggregated level of distinctive NPD phases, phase specific effects are determined and changes in the relevance of the knowledge base during the innovation process are evaluated.

Knowledge bases view builds up and exceeds resource based view considering knowledge as the most fundamental source of competitive advantage. Resource based view argues that resources and competencies which are valuable for the customers, rare, inimitable and organizational embedded are from overwhelming strategic relevance. Enduring heterogeneity in the firms resource base ensures competitive advantage (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993; Amit/Schoemaker, 1993). The knowledge based perspective of strategic management considers knowledge as the most fundamental strategic resource for gaining sustainable competitive advantage. The effectiveness and efficiency of resources depends on how they are applied and combined, which is a function of firm's existing knowledge base. To ensure firm survival in the short term, a firm can choose to exploit its existing knowledge base. Alternatively it can opt to explore new knowledge, which may provide growth and economic success in the long term. Existing knowledge is then used for exploring new knowledge from inside and outside the firm to exploit uncertain opportunities in the future (Levinthal/March, 1981). Knowledge is embedded in different entities like routines, informal and formal networks, systems, organizational culture, corporate identity and employees (Grant, 1996). Although it is recognized, that tacit and explicit knowledge complement each other, a focus is on tacit knowledge.

Because tacit knowledge cannot be codified or easily transferred it is hard to imitate and socially complex. The resulting high degree of casual ambiguity increases potential for the realization of long term competitive advantage. Knowledge is a precondition for understanding the rationale behind the general strategic advantage of knowledge and for building core competencies and intellectual capital.

2. Literature review and theoretical concept

2.1. Knowledge diversity and knowledge coherence

In order to analyze the impact of the firm's knowledge on innovation performance, we concentrate on two properties of the firm's knowledge base: the diversity and the coherence. Knowledge diversity comprises diversity in the knowledge system and principles underlying the nature of products and their methods of production. It is related to a corporation's expansion of its competences on the input side of the firm (Nesta/Saviotti, 2005; Granstrand /Oskarsson, 1994). Trough we concentrate on particularly on the input side of the firm it's expedient to recognize that firm's diversity can be accessed on both, the input level of knowledge as well as on the output level of product market domains. Both levels not necessarily have to be linked. It is commonly recognized that the level of diversity on the input side exceeds the diversification level of product- market portfolios (Gamardella/Torrisi, 1998; Patel/Pavitt, 1997). A minimum degree of congruence between both levels is worthwhile since with increasing congruence between both rises the potential for an efficient use of the firm's knowledge (Grant/Baden-Fuller, 2001).

There is increasing work on the concept of corporate technological diversification, treating technology as a special kind of knowledge. Studies focuses on distinctive technologies and the diversification of firm's technological knowledge while analyzing several potential positive of knowledge diversity on firm's economic and innovation performance (Grandstand/Oskarsson, 1994; Argyres, 1996).

Positive diversification effects discussed in the literature can be differentiated into two groups: risk reduction and enhancement of strategic option trough diversification. Risk reduction results from different sources. First, diversity reduces the risk of getting locked in a competence trap and mitigates core rigidities (Levitt/March 1988, Quintana-García/ Benavides-Velasco, 2008).[1] Second, a diversified portfolio of knowledge domains enables firms to a faster adapt to exogenous shocks in existing knowledge domains. Increased technology fusion, technological convergence and increasing product and process complexity can require knowledge diversity to ensure future competiveness. Diversification, in this context, acts as a kind of insurance against obsolesce of existing knowledge. Third, the access to a diversified knowledge portfolio and the ability of a firm to successfully integrate different pieces of knowledge can constitute an effective market entrance barrier for potential competitors and imitators (Garcia-Vega, 2006). Even in the presence of external acquisition of

[1] Levinthal and March (1993) use the term 'learning myopia' for the same phenomenon. It describes the fact of to becoming trapped in one existing competence field where the firm accumulates a sophisticated amount of knowledge and experience and thereof being blinded to alternative opportunities.

knowledge, diversity of the firm's knowledge base contributes positively to the ability of the firm to identify, integrate and commercially use knowledge from outside the boundaries of the firm (Cohen/ Levinthal, 1990) and reduce the risk of becoming dependent on external knowledge suppliers (Stephan, 2010). The second category of positive diversification effects are strategic options. Strategic options are inherent in every diversified knowledge portfolio. Grandstand (1998) highlights the importance of a diversified technological knowledge base for the generation of new ideas and innovations. Innovation is facilitated by the experimentation with knowledge pieces from different existing or new knowledge domains. Diversity may enhance firms' capability for (re-)combining of existing knowledge stock with new knowledge for developing new breakthroughs. From a dynamic perspective, diversity and the handling of the complexity of a diversified knowledge base within the organization is accompanied by learning dynamics. Those lead to the emergence of the ability to anticipate and evaluate the impacts of new scientific and technological advances early in time when potential application still highly uncertain (Patel/Pavitt, 1997).

Recently there is increasing research strand recognizing coherence as the crucial prerequisite for realizing the potential of positive diversification effects (Piscitello, 2000,2004; Nesta/Saviotti, 2005; Breschi et al., 2003, 2004; Garcia-Vega, 2006). Coherence is a broadly defined, cognitive and firm specific concept. It refers to the interconnectedness of distinct pieces of scientific and technological competencies (Nesta/Saviotti, 2005). Coherence of the knowledge base is received when the activities conducted by an individual firm rely on a common or complementary knowledge base, share common scientific principles or use similar heuristics of search (Breschi et al., 2003). A coherent knowledge portfolio is not received automatically; coherence has to be created actively. Although diversity and coherence are closely interconnected, increased diversity doesn't imply higher coherence. The initiation of an innovation project in a new knowledge domain for example, leads inevitably to an expansion of the diversity of the firm's knowledge portfolio. Simultaneously, coherence changes, but not necessarily in a positive direction. Coherence increases if the underlying knowledge of the initiated new project is strongly interconnected established knowledge base within the firm. Several authors highlight the relevance of coherence when analyzing diversity. For example, Piscitello (2000, 2004) and Valvano and Vannoni (2003), examining patenting activities of large and leading industrial companies, confirm that technological diversification does not proceed in a random way but coherently. Breschi et al. (2003) also provide empirical evidence of non-randomness of diversification. The authors identify knowledge relatedness as a major driver of firm's technological knowledge diversification. The empirically observed coherent diversification pattern, the authors argue, is a consequence of an underlying path dependent learning process.

Particularly, there has been little research on how diversity and coherence of firm's knowledge portfolio affects innovation or economic performance. Nesta and Saviotti (2005) provide empirical evidence for a small sample of 31 pharmaceutical firms, that it is not only the diversity of technological knowledge but also the coherence, what drives innovation output. In a subsequent study,

Nesta and Saviotti (2006) state a positive relationship between knowledge relatedness of firm's knowledge base and firm's market value for a sample of 84 biotechnology firms. Coherent diversification at the knowledge base of the firm has been shown to be positively related with higher innovation and economic performance. Leten et al. (2007) use a panel data set with patent applications from 184 engineering, pharmaceutical, chemical, IT hardware and electronic firms located in Europe, the U.S. and Japan. Instead of a direct effect of coherence on innovation performance the authors test for an interaction effect between knowledge diversity and knowledge coherence on innovation performance. The hypothesis of a moderating effect of coherence on the positive diversity effect is confirmed. The higher the coherence of firms technological knowledge portfolio, the greater the positive diversification effect of technological knowledge on innovation performance.

Nesta and Saviotti (2005) argue that the relationship between diversity, coherence and (innovation) performance of the firm is not limited to technologies as a special subcategory of firm's knowledge base. Diversification and coherence effects can be also expected when classifying knowledge subcategories independent from technological properties, at least in knowledge and innovation intensive industries. For example, related diversification of research activities can be expected to enhance the exploitation of economies of scope through sharing of commentary knowledge and common competencies of two or more research areas through different research projects or research programs.

2.2. New product development process and knowledge dynamics

Existing work on the relationship between knowledge diversity, knowledge coherence and firm's (innovation) success focuses rather on the static firm level than on dynamic intrafirm process level. Adopting this static view is accompanied by an implicit restriction of the analytical framework to static diversity and coherence effects. From a dynamic perspective, product innovation or new product development (NPD) is an organization specific process which is pervaded by significant knowledge dynamics. Knowledge plays a crucial role during the innovation process; knowledge drives innovation output and therefore firm's competitive ability (Spender/Grant, 1996). Though, following Dosi (1988) we define NPD as a process of pooling and integration of various scientific and knowledge sources, embodying different characteristics, in order to create economic value. Closely associated with the high knowledge complexity is the risk inherent in the NPD process. High innovation costs for initiating and pushing forward innovation projects in conjunction with high uncertainty about potential future returns of those projects makes NPD a risky endeavor. Failures in the realization of product innovation projects are often due to a lack of required knowledge. Innovative companies should not miss to evaluate the gap of existing and required knowledge before initiation of the project and continuously during the NPD process (Halman/Kreizer, 1994). The more radical a product innovation project for the firm the higher the percepted discrepancy between existing knowledge and required knowledge. The inherent risk of failure in developing product innovation is not to be underestimated.

Scherer (1999) reports that on average, approximately only half of the innovation projects undertaken by a firm are successful. Since every innovation project is unique for the firm, there is uncertainty concerning knowledge requirements, technological feasibility, market acceptance, management practices etc. at every stage of the NPD. Even after market introduction some risk is still persistent. Halman and Kreizer (1994) state commercially failure rates of launched innovations about 35 percent. Literature has examined some evidence of a strong relationship between diversity, coherence and new product development success. Diversity in firm's research portfolio tends to reduce the risks inherent in the R&D projects. A diversified research portfolio with projects spread over a broad scope of knowledge domains may reduce the risk of failure in NPD. A concisely increasing number of projects associated with different risks provide an opportunity of decreasing the variance associated with the returns on investments in individual projects (Scherer, 1999). In the context of coherence some authors confirm a positive impact of firm's knowledge base on new product success, focusing on project–firm synergy as essential success factors during the NPD process (Cooper/Kleinschmidt, 1993; Kleinschmidt/Cooper, 1991; Song/Parry, 1997; Zirger /Maidique, 1990). Projects with a closer fit to firms existing core knowledge set tend to be more successful (Leonard-Barton, 1992).

As NPD is not a static event but a dynamic process, we argue, inherent knowledge complexity and associated risks are subject to dynamic changes during project progress. Given the previous empirical and theoretical findings, one might expect that kind of relationship between firm's knowledge characteristics and innovation success differs with NPD progress. To make our considerations conceptionally more tangible, we combine the rationale of the knowledge based view in terms of knowledge diversity and coherence with arguments from the NPD literature. The most common approach when analyzing NPD dynamics more in detail is to identify particular activities performed during the NPD process. Consequently, the NPD process can be broken down into subsequent stages with a series of activities in a sequence (Utterback, 1974; Utterback/Albernathy, 1975). Stages of the NPD process are not necessarily carried out sequentially; they can be executed in parallel order or can be overlapping. Furthermore the existence of feedback loops facilitates organizational learning (Pisano, 1994). Every distinctive stage of the NPD process is characterized by clearly defined set of different types of activities (Saren, 1984). Since each individual activity requires the usage and combination of certain knowledge, NPD stages are characterized by an associated knowledge base. Consequently, the knowledge base of individual NPD stages differs in diversity in terms of the breadth and the depth of knowledge (the number of relevant knowledge pieces, e.g. from different disciplines and sophistication of knowledge), but also in the quantity and intensity of relatedness between different knowledge types necessary to perform stage specific activities. Different types of knowledge embedded in activities like research and development, idea management, risk management, technological management, relationship management and knowledge management are all important for NPD but they are located at distinctive stages of the NPD and are motivated for different reasons (Garcia-Vega, 2006). For example, when starting a new innovation project, sophisticated

technological knowledge is form overwhelming importance for carry out R&D activities necessary for a shift of the innovation project to more advanced stages of the NPD. Additionally, to ensure market acceptance some degree of market knowledge is also worthwhile at the beginning of the NPD process. Market knowledge becomes more and more complex with increasing NPD progress and closer proximity to market launch while the amount and intensity of activities drawing on technological knowledge decreases (Danneels, 2002; Verona, 1999). Between both knowledge types is a stage characteristic interconnection. The structure of the knowledge base, including the intensity of interconnectedness between the knowledge types, changes with phase transition.

Based on these considerations we argue that knowledge base, knowledge structure and knowledge dynamics are stage specific and are subject to changes with NPD progress. This results not only from changes in the knowledge base underlying stage specific activity set, but also a consequence of changes in the percepted risks of individual innovation projects during the NPD process. For innovation project in the pharmaceutical industry, DiMasi et al. (1991, 2003) examine phase success rates. The probability that an innovation project will attain marked launch if it enters the given stage of the innovation process varies greatly from one phase to another.

3. Data and Methods

In order to analyze diversification and coherence of the firm's knowledge base through the NPD process we concentrate on the pharmaceutical industry. Particularly, pharmaceutical industry provides a worthwhile framework for this research purpose. Pharmaceutical industry is associated with a high knowledge and innovation intensity where considerable knowledge dynamics takes place (Kandampully, 2002). Innovation process portrays new drug discovery and development as proceeding in a sequence of (possibly overlapping) but clearly definable innovation phases. The realization of spillovers, economies of scale and scope is crucial for successful drug development (Henderson/Cockburn, 1996, Cockburn/Henderson, 2001; Graves/Langowitz, 1993). Additionally, a clear identification of research projects, associated research areas, licensing agreements and NPD history is possible due to the regulation of the food and drug administrations. Data was collected form the database Pipeline (Informa Healthcare). This database provides a comprehensive history of pharmaceutical R&D projects from 1980 until today. Detailed research history of new drug development projects is covered by pipeline. All significant new drug candidates of all major pharmaceutical and biotech firms worldwide are included. At the end of 2012 the database comprises 33599 projects and 3936 companies.

The data offered is based on information from national and international regulatory authorities, public trials registries, conferences, research institutes, journal and press releases and from company communication. Such secondary data are particularly useable in a pharmaceutical context since this industry is characterized by an extensively open communication of the latest (breakthrough) discoveries and inventions via various channels (Henderson/Cockburn, 1997). We combined data

received from pipeline with information gained by analysis of documents and informations from regulation authorities and companies themselves. Drug projects with no progress externally communicated since more than 18 month where set on an inactive status on pipeline ("no development reported"). There was a noticeable proportion of projects not clearly associated to an individual NPD phase. The majority of these projects could be included in the study by taking secondary data into account. Financial data was obtained from the OSIRS database and official firm information, firm communication and annual reports.

We differentiate between three distinctive stages of the NPD. Stage I is preclinical development which comprises synthesis of new compounds and testing in assays and animal models. Stage II covers all activities of clinical (human) testing, which typically comprises three successive phases. In clinical phase I, usually a small number of healthy volunteers are tested with the compound to gather information about absorption, distribution, metabolic effects, excretion, toxicity and dosage. A lager number of persons suffering from the targeted disease are the participants of clinical phase II-trials to gather preliminary data on safety and efficacy. Clinical phasee III trials are conducted on a number of subjects. Large-scale trials are aiming to evaluate optimum efficacy conditions and to identify rare side-effects. Stage III comprises all promising new drug development projects applied for registration at national or international regulatory authorities as well as drugs already registered but pending market launch[2] (DiMasi et al., 2003).

The data set includes NPD phase specific information on the project portfolio of 280 international pharmaceutical companies at the end of 2011. In order to examine phase specific knowledge dynamics we consider all firms conducting at least one innovation project at every of the three defined NPD-stages.

3.1 Dependent Variable

The dependent variable measures innovation stage specific commercial innovation success of a firm. Traditional measures of innovation performance form the literature are R&D intensity (Grabowski, 1968, Garcia-Vega, 2006), Number of patent applications (Scherer, 1984; Leten et al., 2007), number of cited patents, number of technical workers (Gort, 1962). These measures provide valid and general accepted proxis for innovation performance on the firm level. For the research purpose of evaluating knowledge effects on innovation performance with respect particular phases in the innovation process, this proxis are inappropriate. From a conceptual point of view these measurements would be also valid for innovation phase specific studies, but fundamental practical problems arise concerning the availability of relevant data on disaggregated phase level. In our study, the dependent variable is the number of projects licensed out at an individual NPD stage. As innovation is distinguished form invention by the criterion of economic application, the number of licensed-out projects is considered

[2] We concentrate on the new product development process. (Basic) research is a preceding process and not part of the NPD. (Basic) research activities are not subject to our study. An analog differentiation can be found at Henderson/Cockburn, 1996.

as an adequate indicator for stage specific commercial innovation success. It's important to notice, that the dependent variable 'number of licensed out projects' is a measure of commercial success which can be traced back to the knowledge generated through innovation activities in a specific stage of the NPD. This success is strictly linked to this individual NPD stage. The deduction of general statements according to the commercial success of an innovation project after market launch is not possible.

3.2 Technological Diversification

To measure knowledge diversity, the entropy measure as an objective diversity indicator is chosen. Application of entropy measure for determining knowledge diversity requires the differentiation of clearly defined knowledge areas. The present study used a therapeutic-oriented classification derived from the official classification of the European Pharmaceutical Market Research Association (EPhM). This classification differentiates between 14 distinctive therapeutic areas. Therapeutic areas reflect anatomical oriented fields of research defined by specific pharmacological and chemical characteristics. All projects are assigned to one or more therapeutic area of research. The therapeutic area assignment of projects in a firm's project portfolio was used to derive measures of diversification on the input side of the firm. Knowledge diversity is then defined as the spread of the project portfolio over therapeutic areas.

$$DIV_f = \sum_{t=1}^{N} P_{t,s} \log\left(\frac{1}{P_{t,s}}\right)$$

Let P_t, s denote the share of stage s-projects conducted in therapeutic area within in a firm f in relation to the overall number of projects conducted within the NPD stage s. Entropy measure is limited by a lower bounds of 0, the upper bound depends on the number of defined research areas. For 14 therapeutic areas the upper bound is about 1,146.

3.3 Coherence

Recently, there have been various approaches to develop an appropriate measure of knowledge relatedness. The most popular approach is to transmit of the so-called "survivor-measure" proposed by Teece et al. (1994) to the input level of firms. Survivor-measure is originally assigned to firm's output level of product-markets. The rationale behind this measure is quiet intuitive. The basic idea is that economic competition will lead to the disappearance of relatively inefficient organizations from the market. Efficient firms conduct activities in related industries because of economies of scope. It is assumed that industrial activities which are more frequently conducted within the same firm must therefore be more related. The authors calculate the expected value for any firm of simultaneously conducting business activities in a certain pair of industries. If the empirically observed frequency of firm's propensity of being active in a certain industry pair largely exceeds the statistically expected

value, this is interpreted as a strong evidence for a non-random but coherent relationship between the designated industries. Survivor rationale has been also used to measure coherence on the input side of the firm, applying the underling rational to distinctive technological fields instead of industries. Technologies are interpreted as a special type of knowledge whereby technological fields are treated as distinctive knowledge areas. The intensity of relatedness between technological fields is calculated by patent data using patent classification codes or bibliometrics (e.g. Leten et al., 2007; Nesta/Saviotti, 2005). A major methodological disadvantage of this approach is the ignorance of indirect interrelations between two technological fields. Relatedness is not only influenced by the intensity of direct connections between two knowledge bases but also by their indirect connections. Furthermore such measure depends on the absolute number of patents in individual therapeutic areas size of the technological field (in terms of patent applications) and overestimates knowledge links between larger therapeutic areas. Therefore we choose a more complex measure based cosine similarity originally proposed by Engelsman and van Raan (1992) and modified by Breschi et al. (2003). We denote O the whole number all innovation projects of all innovative pharmaceutical firms in a certain period of time. Differentiating knowledge areas by therapeutic areas, each single project is dedicated to one or more therapeutic areas. Multiple physiological effects of a drug can lead to their relevance for innovation activities in more than one therapeutic area. For example acetylsalicylic acid (also known as aspirin) is a mean against headaches but also for blood dilution. Formally, let $I_{tp} = 0$ if project p is relevant in therapeutic area t (t = 1, . . . , 14), otherwise $I_{tp} = 0$ The sum of projects relevant in therapeutic area t is therefore determined by $N_t = \sum_p Itp$. In analogy we indicate the sum of projects relevant in therapeutic area t and u as $J_{tu} = \sum_p Itp\, Iup$ which is a simple count of joint-occurrence. Appling J_{tu} to all innovation projects under consideration for 14 therapeutic areas, this leads to a symmetric 14x14 matrix of Joint-occurrences (**J**). Since **J** is symmetric[3] each column or each line of J constitutes a therapeutic area specific vector of joint-occurrence. Appling the cosine similarity S allows for calculating the similarity of vectors by their angular separation. Cosine similarity is highest for therapeutic areas with identical vectors. This is the case, when therapeutic area 1 shows the same structure like therapeutic area 2 regarding to the mutual joint-occurrence with the remaining 13 areas. Cosine similarity C_{tp} is defined by the correlation between the vectors J_{tk} and J_{uk} divided by their euclidean distance and is therefore interpreted as a correlation coefficient.

$$C_{s,tu} = \frac{\sum_{k=1}^{14} J_{tk} J_{uk}}{\sqrt{\sum_{k=1}^{14} J_{tk}^2}\ x\ \sqrt{\sum_{k=1}^{14} J_{uk}^2}}$$

In line with our theoretical arguments, cosine measure of similarity is calculated for each individual innovation stage, focusing P exclusively on the number of projects conducted in stage s (s=1,2,3). This

[3] This is true since no differentiation between the included therapeutic area associated with one specific project is made when calculating I_{tp}.

allows counting for knowledge dynamics and changes in the interrelatedness between distinctive research areas due to different activity structures during individual stages of the NPD progress.

Coherence of stage specific project portfolio of firm f is calculated in two subsequent steps. First, for every therapeutic class and stage, a weighted average of relatedness (WAR) is build which represents a firm specific measure of the average commonalities and complementarities in the knowledge base of the therapeutic area t and any therapeutic areas in which the firm f conducts projects in NPD stage s:

$$\mathrm{WAR}_{\mathrm{f,s,t}} = \begin{cases} \dfrac{\sum_{t \neq u} \mathrm{C}_{\mathrm{t,u}} O_u^{f,s}}{\sum_{t \neq u} O_u^{f,s}} & f\ddot{u}r P_e^a > 0 \\ 0 & sonst \end{cases} .$$

The overall coherence of firms knowledge base in NPD phase s is defined as the weighted average of the $\mathrm{WAR}_{\mathrm{f,s,t}}$ measures: $COH_{f,s} = \frac{\sum_{t=1}^{14} O_t^a * \mathrm{WAR}_{\mathrm{f,s,t}}}{\sum_t O_t^a}$. $COH_{f,s}$ equals 0 if there are no knowledge complementaries and commonalties in the phase specific knowledge base of the firm f. $COH_{f,s}$ reaches its maximum of one for a fully coherent knowledge portfolio in phase s. For the calculation of WAR we considered all projects available in the Pipeline database.

3.4 Control Variables

The empirical model controls for other potential effects which are likely to influence commercial innovation success in different phases of the NPD. On the phase level of individual NDP phases we control for innovativeness of conducted projects since innovativeness is expected to be positively related with commercial innovation success. On the firm level, R&D expenditure or the R&D-intensity is commonly used as proxy for innovativeness (Nesta/Saviotti 2005; Garcia-Vega, 2006; Quintana-García/A. Benavides-Velasco, 2008). On the phase level the sum of R&D budgets of individual projects conducted in a specific phase would be corresponding valid measurement of innovativeness. Such internal budget data is rarely available because there is no disclosure requirement. Thus, to control for innovativeness effects, we take the accumulated number of new chemical entities (NCE) in relation to the accumulated number of all successful drug projects for every individual NPD phase into account. A new chemical entity is a genuinely new drug with a new chemical structure which was not previously known. They go far beyond simple modifications or improvements of existing drugs concerning dosage, formula or chemical structure. NCE's provide significant therapeutic advances and reflects the firms R&D ability to deal with complex innovation processes and to create radical new knowledge and innovations (Cardinal, 2001). Furthermore is expected that NCE's are more attractive for licensing partners and therefore tend to be more commercially successful than non-NCE's.

A further firm specific dummy is included to control for size effects. An increasing firm size is expected to be associated with higher potential for economies of scale as well as with a higher amount of R&D expenditures which leads to an extension firm's innovation project portfolio. We classify the sample firms according to the Scheme of the European Commission by sales into three size classes (Table 1). Since we analyze the project portfolio of pharmaceutical firms at the end of 2011 we calculate the average of sales from 2010 to 2012 to account for year specific fluctuations. For all firms, sales were converted into euro, based on the respective exchange rate at the end of every fiscal year.

Table 1. Size distribution

Category	Sales in mio. Euro	No. of sample firms	No. of firms/total	% of total licenced out R&D projects
Small	≤ 10	118	42,14	9,8
Medium	> 10 and ≤ 50	88	31,43	26,89
Large	> 50	74	26,43	63,2
Total		280	100	100

As a further firm-level variable we introduce a variable LAUN as a measure of the size regarding the portfolio of projects already successfully introduced into the marked. Firms with a large portfolio of marked drugs are expected to be more experienced in conducting innovation activities. They rely on accumulated prior knowledge and advanced competencies with respect to new product development. Their experience makes them more effective in conducting new drug development projects than less experienced firms.

3.5 Descriptive Statistics

Table 2 contains the descriptive statistics of the independent variables and the dependent variable. The mean of knowledge diversification is highest in stage 2 (0,42) and nearly equal for stage 1 and 3 (0,34 and 0,33). The average coherence of the project portfolio decreases with NPD progress. The mean of coherence is 0,39 for stage 1, 0,38 for stage 2 and 0,27 for stage 3. As one may expect, firms diversify their project portfolio in rather a coherent than a random way. The dependent variable LIC pass its peak in stage 2 with an average of 2,01 licensed out projects. In stage 1 the average value of LIC is 1,38 and in stage 3 1,64.

Table 2. Descriptive Statistics

Variable	DIV1	DIV2	DIV3	COH1	COH2	COH3	LIC1	LIC2	LIC3	N
Description	knowledge diversity of phase s (s={1,2,3})			knowledge coherence of phase s(s={1,2,3})			numer of licened out projets in phase s (s={1,2,3})			
Mean	0,34	0,42	0,33	0,39	0,38	0,27	1,38	2,01	1,64	
Std. Deviation	0,30	0,28	0,29	0,32	0,24	0,22	3,27	4,22	2,74	280

The coefficients of correlation between the variables of interests are presented in Table 3. A higher diversity the firm's knowledge base can be positively associated with a higher level of coherence. This relationship holds true for all innovation phases. Furthermore the level of diversity and coherence once realized in one NPD stage seem to influence subsequent NPD stages. This could indicate a coherent diversification pattern during the NPD process.

Table 3. Correlation Matrix

Correlations									
	DIV1	**DIV2**	**DIV3**	**COH1**	**COH2**	**COH3**	**LIC1**	**LIC2**	**LIC3**
DIV1	1								
DIV2	,559**	1							
DIV3	,521**	,553**	1						
COH1	,787**	,435**	,317**	1					
COH2	,242**	,661**	,245**	,298**	1				
COH3	,370**	,472**	,819**	,234**	,328**	1			
LIC1	,464**	,277**	,483**	,190**	,003	,175**	1		
LIC2	,462**	,324**	,478**	,213**	,039	,145**	,767**	1	
LIC3	,430**	,345**	,618**	,226**	,089	,262**	,610**	,663**	1

**. Correlation is significant at the 0.01 level.

4. Empirical Results

The dependent variable is the number of licensed-out projects in a specific phase of the NPD (LIC_s).For model selection we take three properties of LIC_s into account. First, LIC_s is a count variable which takes only nonnegative integer values. Second, LIC_s is characterized by some overdispersion regardless of the NPD stage under consideration. Third, there are excessive zeros in the distribution of LIC_s. Based on these considerations a zero-inflated negative binomial regression was employed. The idea behind a zero inflated model is excess zeros are generated by a separate process from the count values. Excess zeros are modeled independently. A zero-inflated model assumes that zero outcome is due to two different processes. In the research context of this paper this means that there are two processes that a firm can follow: licensing-out vs. not licensing-out. If the firm is not licensing-out, the only outcome of this process is 0. Contrary, licensing-out is a count process. The expected count is expressed as a combination of the two processes.

Table 4 presents the estimation results of the relationship between commercial innovation success, knowledge coherence and knowledge diversity in every for the three NPD stages under consideration. The estimation for every stage is represented by an own column. The numbers in italics are t-statistics. All stage specific regressions contain six variables. DIV_s accounts for the knowledge diversity in NPD state s (s = 1,2,3), COH_s is the measure of the phase s' knowledge coherence (s=1,2,3), NCE_s is a control for phase specific innovativeness of firms knowledge base (s=1,2,3). LAUN controls for sophisticated knowledge effects on the overall firm level and is constant for an individual firm. Furthermore the dummies d_large and d_medium were included to take size effects into account.

d_large is set to 1 if firm is categorized as large firm, 0 otherwise. d_medium is set to 1 if firm is categorized as medium, 0 otherwise. Therefore, small firms were treated as the baseline category.

The left hand site of the table shows the coefficients of the variables. The coefficients of a zero inflated negative binomial regression must be interpreted with caution. Coefficients in a non-linear regression are only indicators for the direction of impact from an independent variable on the dependent variable. In the linear regression model, the relevant slope coefficient equals the marginal effects. For nonlinear models, this is no longer the case (Cameron/Trivedi, 2005, p. 333).

No interpretations about the concrete level of influence between the independent variable on the dependent variable can be made by coefficients. To determine the impact level, marginal effects have to be calculated. Marginal effects provide a good approximation to the amount of change in the dependent variable resulting by a 1-unit change in the independent variable given average values on the independent variables.[4] They are presented on the right hand site of Table 4.

The results in Table 4 support the hypothesis that knowledge diversity positively affects commercial innovation success. This holds true for all stages of the NPD. In all stages the coefficients of DIV is positive. Differences in the effect size are indicated by the marginal effects. The strongest relevance of knowledge diversity for commercial innovation success can be stated for stage 3, the stage most closely to market launch. The lowest impact of knowledge diversity on commercial innovation success is in stage 2. The marginal effect of knowledge diversity on commercial innovation success in stage 2 is nearly half as high as in stage 3. Knowledge coherence shows a significant and negative impact on commercial innovation success in all three stage specific models. Marginal effects reveal the highest negative impact for NPD stage 2 (-1.140), followed by stage 1 (-1.066) and stage 3 (-1.052). An increased coherence negatively influences commercial innovation success during the whole pharmaceutical innovation process. Furthermore, knowledge diversity and knowledge coherence seems to develop opposite performance effects with NPD progress. The number of launched projects has a slightly positive but significant impact on commercial innovation success during all phases of the NPD. The impact of launched projects (LAUN) as proxy for former and sophisticated knowledge held by a firm, shows a similar pattern than coherence effects on commercial innovation success. The effect of the portfolio of drugs already available in the market is highest for stage 2 (marginal effect 0,02), followed by stage 1 (marginal effect 0,005) and stage 3 (marginal effect 0,004). The number of new chemical entities is significant only for stage 1. The coefficient is positive; the marginal effect on commercial innovation success is at 0.404. For stage 2 and stage 3, the number of NCE projects actually conducted has no significant influence on the innovation success of each innovation phase.

The introduced size dummies are positive and highly significant for all NPD phases. The baseline category are small firms, so we include d_large for large firms and d_medium for medium sized firms in the subsequent models. Marginal effects have to be interpreted with respect to the baseline category.

[4] Marginal effects at means are used. They can be differentiated from average marginal effects (AME). Calculation of AME based on all data from the sample, not on their means.

The general empirical observation of size impacts on innovation success in every phase is supportive concerning the assumption of positive knowledge effects, regardless to specific phases. On the level of individual NPD stages a similar effect pattern like coherence can be identified. For stage 2 the size effects are stronger than for stage 1 and 3. Marginal effect of 2.395 in stage 2 for large firms (d_large) express that, for two hypothetical firms with average values on the independent variables, the predicted value of commercial innovation success is 2.4 greater in terms of the absolute number of licensed out projects for large firms than for smaller firms. The number of licensed out projects by medium sized exceeds the number of licensed out projects of small firms by 1.6 projects (given average values on the independent variables) in NPD stage 2. The second highest effects can be observed for stage 1 with a marginal effect of 1.4 for large firms and a marginal effect of 0.9 for medium sized firms. The least size effect is achieved in the last innovation phase, stage 3. Marginal effect of large firms is about 0.7, for medium sized firms about 0.6.

The econometric issue of endogeneity can arise because of the phase specific variable knowledge diversity. Knowledge diversity of one innovation phase can depend on commercial innovations success since financial returns from licensed-out projects could be re-invested in further knowledge diversification. To deal with this issue, we follow an approach suggested by Gacia-Vega (2006). This approach is based on the following intuitive idea: Firms with a stable knowledge portfolio and approximately equal diversity in all stages of the NPD are expected to not re-invest financial returns from project licensing activities into knowledge diversification. If the relationship between knowledge diversity and number of licensed-out projects for the subsample of stable diversified firms is significant, the proposed relationship between the two variables can be assumed as causal given a sufficiently reduced endogeneity problem. Stable diversified firms are defined by 15 percent of the maximum diversity range (=1,14), which lead to a maximum standard deviation of 0,172. 116 firms fall in the category of stable knowledge diversity during the three innovation phases under consideration. Results of the subsample regression support causal relationship of commercial innovation success depending on knowledge diversity. Results are presented in Table 5 of the Annex.

Table 4. Binomial negative estimation of the number of licensed-out projcets

Dependent Variable	**Number of licensed-out projects**					
	Coefficients			Marginal effects dy/dx		
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
DIVs	2.59***	1.281***	3.000***	1.557***	1.412***	2.904***
	5.34	2.90	8.23	5.03	2.90	8.00
COHs	-1.773***	-1.034**	-1.084**	-1.066***	-1.140**	-1.052***
	-3.53	-1.99	-2.27	-3.42	-2.00	-2.20
NCEs	0.673***	-0.114	-0.203	0.404***	-0.125	-0.198
	3.09	-0.53	-1.08	3.03	-0.53	-1.08
LAUN	0.009***	0.018***	0.004**	0.005***	0.020***	0.004**
	2.99	5.29	2.00	2.83	4.87	1.96
d_large	1.476***	1.427***	0.647***	1.372***	2.395***	0.744***
	5.05	6.06	3.22	3.60	4.23	2.76
d_medium	1.144***	1.105***	0.514***	.897***	1.573***	0.555**
	4.19	5.21	2.80	3.42	4.18	2.55
constant	-1.206***	-0.888***	-1.034***			
	-2.73	-4.02	-6.13			
Log likelihood	-330.1677	-428.3513	-387.895			
Sample	280	280	280			
Nonzero obs.	109	145	154			
Zero obs.	171	135	126			
LR chi2	151.26					

z-statistics in italics; d_large: dummy variable, 1 if firm is categorized as large firm, 0 otherwise. d_medium: dummy variable, 1 if firm is categorized as medium, 0 otherwise.
* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level.

Marginal effects are very popular, especially in economics. One big problem with marginal effects, however, may be that their calculation only produces a single estimate of the marginal effect. Since 'average' is a defined value, under some circumstances average values can distort difference in effects across different firms. More realistically, the relationship of variables on commercial innovation success varies with the characteristics of the firm, e.g. coherence impacts could be much greater for older larger than for smaller or for more than for less diversified firms. Marginal effects at representative values (MERV) are particularly usable in terms of dealing with this issue. MERV indicates how the effects of variables vary by changing characteristics of the firm. In the given research context, a particular interest is on the comparison of NPD phases with respect to the marginal effects of coherence at different levels of diversity. Figure 1 shows the results of this marginal effect analysis.

Figure 1. Marginal effects of coherence by different levels of diversity

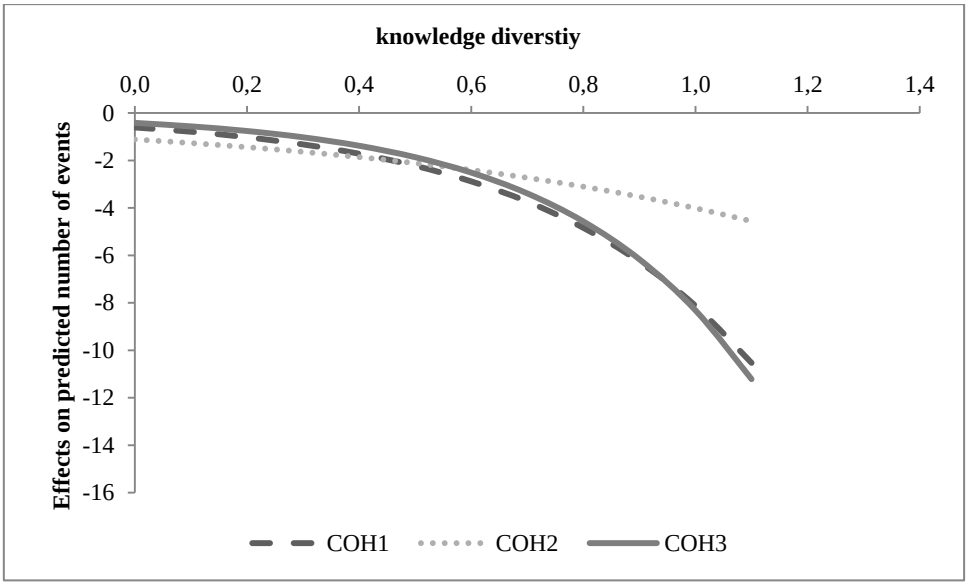

Figure 1 provides some insights into the knowledge dynamics during the NPD and within the individual stages. First, for all stages, the impact of coherence on commercial innovation success is substantial. For each individual stage of the NPD, the marginal effects of coherence on the number of licensed-out projects is negative and increases disproportionately with an increased level of knowledge diversity. Taking one individual stage as unit of analysis reveals the dynamics between knowledge diversity and knowledge coherence within one stage. For innovation stage 1 for example, the marginal effects of coherence at the diversity level of 1,1 is 4,7 times larger than on a diversity level of 0,5. Compared to an even lower diversity level of 0,2 reveals a 10,3 times lager marginal effect of coherence for a given knowledge diversity of 1,1. Similar observations can be made for the two remaining innovation stages. The pattern of relationship between diversity and marginal coherence effects seems to be very similar between stage 1 and stage 3. For stage 3, the curve of marginal effects of coherence is considerably flatter. Obviously, in this phase which is characterized by high risks and

large investments in the form of sunk costs (e.g. clinical trials), the negative impact of coherence exceeds the negative impact of coherence in less risk and capital intensive stage 1 and 3. This changes with increased knowledge diversity. Since the intensity of marginal effects of coherence in stage 2 increases less strongly in stage 1 and 3, an intersection of the functions exist. From a diversity level of approximately 0,57, marginal effects of coherence in stage 2 falls below the marginal coherence effects of stage 1 and 3.

5. Conclusion and Discussion

This study examined the dynamics and effects of knowledge diversity and coherence on commercial innovation success at different stages of the new product development process. Drawing on the rational of the knowledge based view as well as on literature of technology management and new product development process we analyzed the performance impacts of firm's knowledge base from a process perspective. This dynamic level of analysis enabled us to address a persistent research gap since previous work focus primarily on the static firm level, assuming consistently knowledge effects during the NPD.

Our main findings are supportive to the hypothesis that NPD progress and the stage of NPD matters when determining the impacts of firm's knowledge base on commercial innovation success. In a first step, we provide empirical evidence for a causal relationship between knowledge diversity and coherence of the new product development process for all phases of the new product development process. Increased knowledge diversity results in higher commercial success, regardless to the innovation phase under consideration. A diversified knowledge portfolio ensures risk diversification and provides sufficient potential for taking various strategic actions resulting in commercially successful projects. The impact of knowledge diversity on commercial innovation success is the lowest in innovation stage 2. Conducting an inter-phase comparison, stage 2 is characterized by the highest average of diversification and the lowest standard deviation of diversity. Knowledge diversity in this phase is from significant but from more limited relevance for commercial innovation success.

The differences of diversity dynamics between innovation stages become more evident when taking marginal effects at representative values into consideration (see annex, Figure 2). Obviously, in stage 2 the potential for realizing positive diversification effects is limited. One possible explanation could be found in the cost and risk intensive clinical trials, challenging firm's resource constraints.

Following this argumentation, diversity is most worthwhile for commercial innovation success in phase 3. The number of non-zero observations (Figure 2, annex) indicates a higher willingness to license in and license out in this phase close to market launch. In phase 3, disproportionately commercial innovation performance effects can be realized by adopting measures to increase knowledge diversity, e.g. putting forward the exploitation of multiple physiological effects or actively conducting project portfolio management (Figure 2, annex).

Coherence has a consistently negative impact on commercial innovation success. This result initially contradicts prior empirical work with a consensus on a positive relationship between coherence and innovation performance (Nesta/Saviotti, 2005; Leten et al., 2007). The main difference between these studies and our work lies in a different level of analysis. Shifting the research focus form a pure static framework to a dynamic process context makes variables and results only partially comparable. Existing studies use traditional, static innovation performance indicators like number of patents (Leten et al., 2007) or number of citation-weighted patents(Nesta/Saviotti, 2005). In our study, we focus on the dynamic process level, choosing a process related indicator for determining innovation stage specific success. Our indicator 'licensed-out projects' is not an indicator for the overall market or research success of an innovation project. It concentrates on the assessment of the knowledge generated through innovation activities in a specific innovation phase. It regards to the attractiveness of generated knowledge for external and commercial licensing partners. Attractiveness could for example arise from novelty or precepted future scientific and commercial potential of knowledge.

The highest negative effect of coherence on commercial innovations success is empirically proved for stage 2. The consideration of the marginal effects (Table 5, annex) reveals that in each NPD phase investments in coherence are not conducive in terms of increasing commercial innovation success. Some unrelatedness in the project portfolio of pharmaceutical firms seems to foster commercial innovation success. Some explanations for these results can be found in the literature. Strategic motives of the Originator can lead to a restrictive license-out policy. Especially in strategic significant knowledge and competence domains, licensing out is not reasonable (Willcocks et al., 1995). If a firm is characterized by high knowledge coherence, it can be assumed that there is a strategic focus on selected knowledge domains. This focus leads to a behavior of keeping most projects in these domains in-house until market launch. Strategic motives of the Licensee can also explain our observation to some extent. Given our prior argumentation, an increasing degree of coherence can be associated with a research focus of the firm. A strong research focus supports the development of competitive advantage in selected research areas. This competitive advantage can act as an entry barrier for new entrances of established pharmaceutical firms or new firms in this research field by own innovation activities as well as by licensing-in-strategies (Wernerfelt, 1984).

Our findings are also relevant for managerial practice. The results points out the relevance of knowledge dynamics during the innovation process as a key element of successful diversification strategies. Diversification and coherence should be considered during the whole NPD process. Diversity and coherence could be actively decreased or increased by concrete measures like fostering the awareness and exploitation of multiple physiological effects covered by an individual drug or systematic program and a prospective project portfolio management. Besides the implications for technological management, the results are particularly useful concerning organizational design choice which aims to secure the realization of potential diversity and coherence effects.

From an academic point of view we contribute to an extensive research gap. We explicitly consider innovation and knowledge effects from a process perspective. Previous studies in this context focus on static firm level, neglecting the analysis of changes in knowledge base and knowledge characteristics during the innovation process. Furthermore we address the relevance of coherence when determining innovation success. Both research directions, the process perspective of knowledge based innovation as well as the analysis of coherence patterns and effects, are interesting and promising research field. In a quantitative approach we identified general interactions and effects. For deepen the understanding of the rationale behind the causal relationship, a subsequent qualitative empirical study is meaningful. The combination of different literature streams, especially the knowledge based view and the NPD literature offers a fruitful framework for further process level oriented research on innovation success.

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Annex:

Figure 2: Marginal effects of knowledge diversity

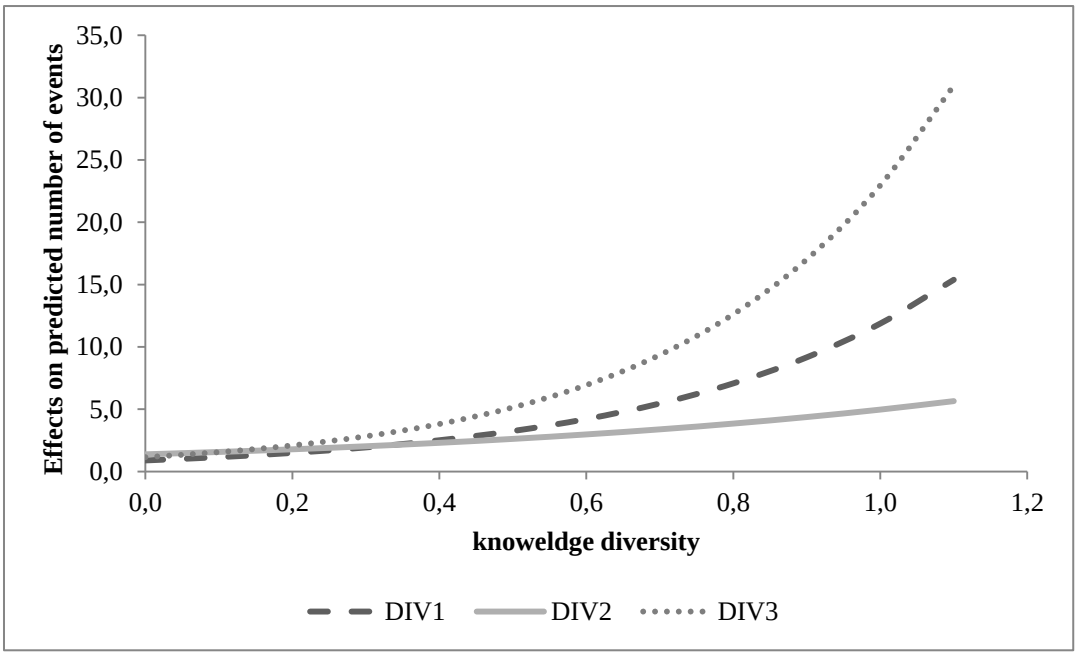

Figure 3: Marginal effects of knowledge coherence