Arvanitis, Spyridon; Wörter, Martin

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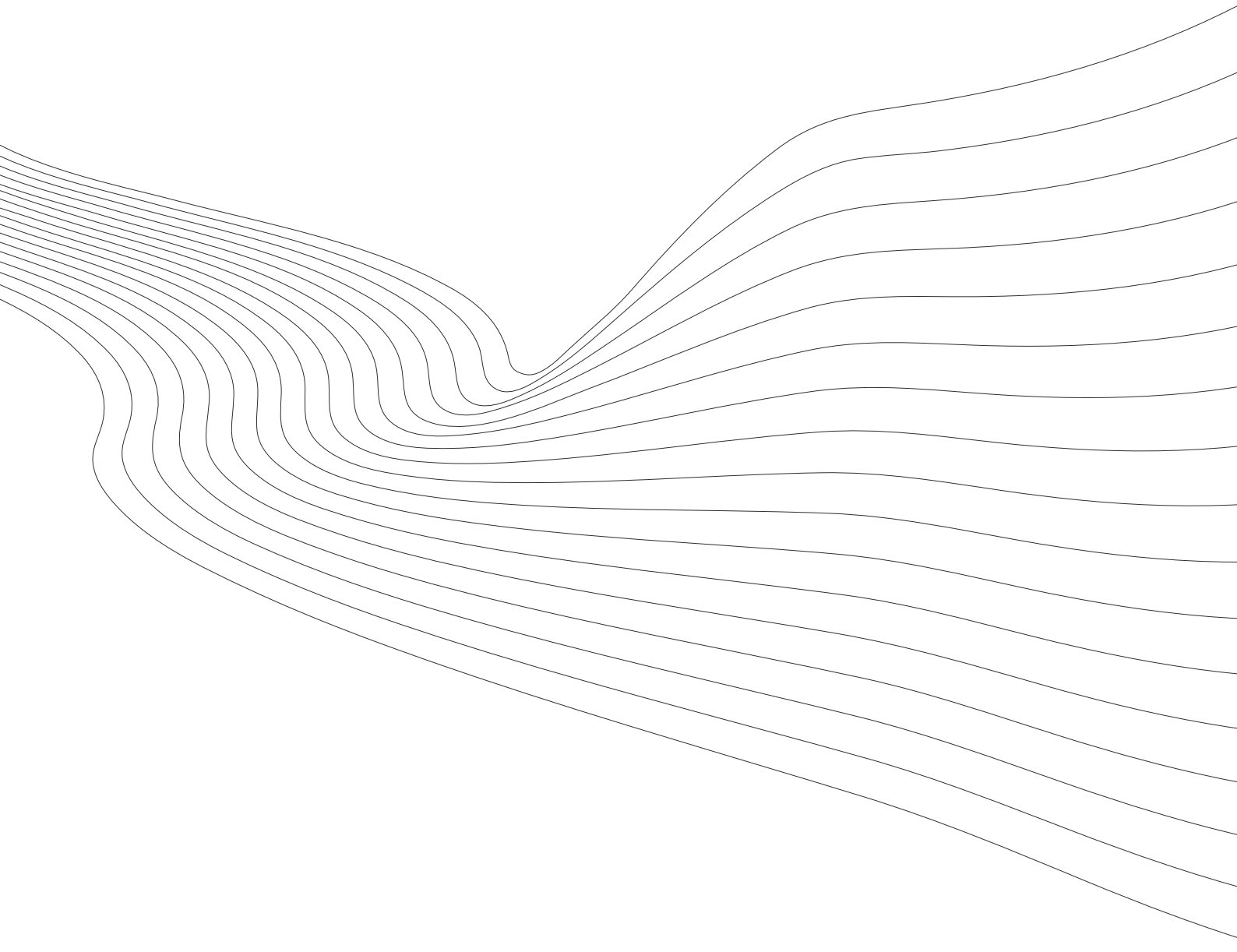

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ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

KOF

ETH Zurich
KOF Swiss Economic Institute
WEH D 4
Weinbergstrasse 35
8092 Zurich
Switzerland

Phone +41 44 632 42 39
Fax +41 44 632 12 18
www.kof.ethz.ch
kof@kof.ethz.ch

Exploration or Exploitation of Knowledge from Universities: Does It Make a Difference?

Spyros Arvanitis
ETH Zurich, KOF Swiss Economic Institute
CH-8092 Zurich
Phone: +41 44 632 51 68
E-Mail: arvanitis@kof.ethz.ch

Martin Woerter
ETH Zurich, KOF Swiss Economic Institute
CH-8092 Zurich
Phone: +41 44 632 51 51
E-Mail: woerter@kof.ethz.ch

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Abstract

In a first step, we developed based on existing theoretical and empirical literature a series of hypotheses with respect to the relative importance of possible determinants of exploration and exploitation of knowledge in collaboration with universities and tested them on Swiss firm data. In a second step, we investigated the impact on innovation performance of knowledge exploration versus knowledge exploitation. We obtained a clear pattern of the differences between 'exploration'-oriented and 'exploitation'-oriented firms. We found that exploration-oriented firms have a greater knowledge absorptive capacity, are technologically more diverse, and they are less exposed to intensive price competition compared to exploitation-oriented firms. We further found a positive effect on innovation performance for exploration-oriented firms but not for those that were exploration-oriented.

Key words: knowledge exploration; knowledge exploitation; innovation

JEL Classification: O31

1. Introduction

Starting point of the paper is the distinction between exploitation and exploration of technological knowledge as introduced in March (1991) and Levinthal and March (1993). In line with this literature, attention is focussed on the differences between knowledge development and knowledge utilization, relating the concepts of exploration and exploitation to the scale and scope of knowledge generated or external acquired relative to a firm's existing knowledge base. In this study we apply this distinction specifically to knowledge acquired from universities. In this sense, we are interested in investigating which type of firm acquires additional external knowledge from universities for the purpose of exploring new knowledge and which for the purpose of exploiting existing knowledge. This is relevant not only for understanding in general firms' knowledge acquisition strategies in terms of resource endowment and capabilities as well as their impact on innovation performance but also for the specific situation of knowledge and technology transfer from universities.

Thus, the motivation for this study is twofold: first, we want to investigate which type of firm pursues knowledge acquisition from universities for the purpose of exploring and generating new knowledge and which for the purpose of exploiting existing knowledge; second, if there are discernible differences as to important firm characteristics between the firms that focus on exploration and those that concentrate on exploitation, this would be also relevant for the impact of knowledge and technology transfer activities and, as a consequence, for the assessment of such activities from the point of view of economic policy.[1] We would then expect that exploitation-oriented activities would show performance effects already in the short run, contrary to exploration-focused activities, for which mostly only long-run effects would be expected.

In a first step, we developed based on existing theoretical and empirical literature a series of hypotheses with respect to the relative importance of possible determinants of exploration and exploitation activities in collaboration with universities and tested them on Swiss firm data. In a second step, we investigated the impact on innovation performance of knowledge exploration versus knowledge exploitation.

Our main contribution to empirical literature is the integrated approach of the investigation of (a) the factors that may influence a firm's decision in favour of either exploration or exploitation of knowledge in collaboration with universities and (b) the relationship between exploration and exploitation of knowledge and the innovation performance of firms.

The paper is structured as follows. Section 2 refers to the conceptual background of the study and to the related empirical literature and ends with the formulation of the research

[1] In earlier studies we have investigated the determinants of knowledge and technology transfer activities of Swiss firms (Arvanitis et al. 2011) as well as their impact on innovation and economic performance (Arvanitis et al. 2008; Arvanitis and Woerter 2009).

hypotheses. Section 3 is devoted to the presentation of the model specification. In section 4 we describe the data. In section 5 the results are presented and section 6 concludes.

2. Conceptual framework and related empirical literature

2.1 Exploration versus exploitation: the main idea

2.1.1 Basic concepts and definitions

Earlier research has defined the relationship between exploitation and exploration of technological knowledge as the balancing between refinement of an existing technology and invention of a new one (Winter 1971; Levinthal and March 1981). More recently, March (1991) developed further this idea in its seminal paper, in which he analyzed the potential trade-off between exploitation and exploration as two alternative investment opportunities. As this author puts it, "choices must be made between gaining new information about alternatives and thus improving future returns (which suggests allocating part of the investment to searching among uncertain alternatives), and using the information currently available to improve present returns (which suggests concentrating the investment on the apparently best alternative)" (p. 72). In a subsequent paper, Levinthal and March (1993) made this notion more specific, stating that exploration involves "a pursuit of new knowledge of things that might come to be known", while exploitation is related to the "use and development of things already known" (p. 105).[2] As a consequence, attention was focussed on the distinction between knowledge development and knowledge utilization, relating the concepts of exploration and exploitation to the scale and scope of knowledge generated or extern acquired relative to a firm's existing knowledge base.

2.1.2 The exploitation/exploration balance

Exploration and exploitation activities compete for scarce resources and the firm has to allocate resources among them. The resulting trade-off is an act of precarious balance. As March and Levinthal (1993) state it: "An organization that engages exclusively in exploration will ordinarily suffer from the fact that it never gains the returns of its knowledge. An organization that engages exclusively in exploitation will ordinarily suffer from obsolescence" (p. 105). Thus, the central problem confronting firms is to engage in sufficient exploitation to maintain and increase short-term performance and, at the same time, to devote enough resources to exploration in order to ensure long-term survival. This requires a mix of exploitation and exploration activities, which is of course difficult to specify (see, e.g., Gupta et al. 2006; Lavie et al. 2010). In economic terms, the trade-off refers to the balance between

[2] The notions of exploration/exploitation have been studied in a wide variety of literature such as organizational learning and knowledge acquisition of enterprises, which is also the subject of the present paper, organizational design, knowledge management, and adaptation (see Lavie et al. 2010 for a comprehensive survey of the organization-oriented literature; Li et al. 2008 for a survey of related conceptual questions.) For the embedment of this approach in the evolutionary theory of organization see, e.g., Zollo and Winter (2002).

short-term specialization advantages (cumulative knowledge generation process, experience gains, etc.) and the ability in the long-term to develop new perspectives that allow firms to avoid technological lock-ins (see, e.g., Arthur 1989).

2.1.3 Determinants of exploration/exploitation

Given the inherent tension between exploration and exploitation, an analysis of the factors that drive these contradictory activities appears to be an interesting research topic. As Lavie et al. (2010) in their literature survey write: "There has been little attempt to uncover why some organizations emphasize exploration, while others pursue exploitation. Empirical research has produced limited or mixed evidence on the causes of exploration and exploitation" (p. 118). In this sense, it would be interesting to investigate which type of firm acquires external knowledge for the purpose of exploring new knowledge and which for the purpose of exploiting existing knowledge. Existing literature has identified a series of factors as important antecedents of exploration and exploitation that are briefly reviewed in the next paragraphs.

Absorptive capacity. A firm's ability to assess the value of external knowledge and apply it in combination with its internally created know-how, which is its absorptive capacity (Cohen and Levinthal 1989, 1990), is related primarily to exploration activities (Lavie et al. 2010; Lichtenthaler and Lichtenhaler 2009). A high absorptive capacity enables firms to detect and explore for their own purpose new emerging technologies (e.g. nanotechnology, biotechnology) and associated market opportunities. Of course, the further exploitation of existing knowledge (along a given technological trajectory) acquires also the use of external knowledge, therefore the ability to absorb such knowledge, but to a lesser extent as in case of exploration.

Technological diversification. The relationship between *technological diversification* and exploration and exploitation of knowledge is ambiguous. On the one hand, it is plausible that firms with a wide portfolio of technological activities are more likely to get engaged in exploration because they can have lower exploration costs than highly specialized firms. Their broad knowledge spectrum could enable them to detect earlier than other firms opportunities for new knowledge. On the other hand, specialization could also decrease the marginal costs of exploring new knowledge, especially if it is within a technological paradigm or trajectory.. However, it is also likely that decreasing search costs within a paradigm come along with increasing costs for knowledge exploring activities in other fields of investigation. Since specialized firms accumulate knowledge and experiences, it is also likely that they have advantages in exploiting existing knowledge. Consequently, the effect of technological diversification on exploration and exploitation of knowledge in collaboration with universities is not "a priori" clear.

Appropriability conditions. The ability to appropriate the revenues of innovations depends on the appropriability conditions, that is the effectiveness of protection from imitation through

available formal (e.g., patents) and informal means (e.g., leadtime, product complexity). When appropriability is low, investment in exploration would be discouraged at a larger extent than investment in exploitation, the outcomes (e.g. new products) of which can be easier protected by available informal means. As Lavie et al. (2010) write: "Under such conditions [of a weak appropriability regime], the value of exploration is diminished so that organizations may withhold their investment in exploration and focus on exploitation" (p. 120).

Competitive intensity. The relationship between *competitive* pressures and the incentives to exploit and/or explore knowledge in collaborations with universities is ambiguous. The Schumpeterian view would suggest that a certain level of market power is necessary for a firm to be motivated to bear the risks of exploration. But there are limits to this effect. "In the long run, however, the use of power to impose environments is likely to result in atrophy of capabilities to respond to change" (Levinthal and March 1993, p. 102). A second line of argumentation suggests that competitive pressures would enhance incentives for exploration that can drive change and reveal new sources of competitive advantage, thus improving a firm's relative position vis-à-vis competitors (Levinthal and March 1993; Lavie et al. 2010). Given that innovation activities are mainly financed with the cash-flow (see Hall 1992) of a firm and that competitive pressure, especially intensive price competition, reduce the price-cost margins of firms and as a consequence lowers their cash-flow, it is likely that intensive price competition increases the probability of the usually less expensive exploitation of knowledge and decreases the probability of the usually more expensive exploration of knowledge.

Firm size. As Lavie et al. (2010) mention "conflicting findings exist concerning the impact of organizational size on the tendency to explore versus exploit" (p. 124). On the one hand, with increasing size, firms tend to become less flexible and less adaptable to changes, leading to knowledge exploitation along existing trajectories, while restricting explorative search for new opportunities. On the other hand, larger organizations may have better access to internal and external resources that allow a more effective and less expensive search for new knowledge. We sympathize with the latter hypothesis, which is in accordance also with the empirical evidence for overall innovation activities.

Firm age. Younger firms are less strongly dedicated to existing technologies along known technological trajectories as older established enterprises. Thus, young organizations are more likely to invest in exploration (Lavie et al. 2010). Older firms rely more on their existing knowledge and experience, so that they are stronger inclined to engage in exploitation rather than exploration (Rothaermel and Deeds 2004).

2.1.4 Performance effects of exploration versus exploitation

The theoretical expectation is that "Adaptive systems that engage in exploration to the exclusion of exploitation are likely to find that they suffer the costs of experimentation without gaining many of the benefits….Conversely, systems that engage in exploitation to the exclusion of exploration are likely to find themselves trapped in suboptimal equilibria" (March 1991, p. 71). As Levinthal and March (1993; based on March 1991) noted: "The returns to exploitation are ordinarily more certain, closer in time, and closer in space than the returns to exploration". Firms that invest only (or primarily) in exploitation may show a higher short-term performance than firms that engage in exploration. However, such short-term gains may cause negative long-term performance consequences, since investing only in exploitation reduces adaptability to future technology changes.

2.2 Related empirical literature

2.2.1 Determinants of exploration/exploitation

Related empirical research comes mostly from the management and organization literature. Cohen et al. (2002) applied the concepts of exploration/exploitation on the knowledge acquired by firms by distinguishing between external information sources that are rated by firms as an important stimulus to the "initiation of new projects" (e.g., public research) and such external sources of information that contribute to "R&D project completion" (e.g., clients). They collected by means of a survey, data for 1267 U.S. firms for the year 1994. They found that publications/reports, licensed technology and cooperative/joint ventures were more relevant for exploitation-oriented activities, while the hiring of recent graduates was more important for exploration activities. A further finding was that firm size correlated positively with both exploitation and exploration, also that being a start-up indicated a higher likelihood of exploitation than of exploration.

Rothaermel and Deeds (2004) in a study for 325 U.S. Biotech firms analyzed the factors that determine the number of exploitation-oriented alliances. The results showed positive effects for the number of patents, firm age, technological diversity, firm size, and the firm being public.

Sidhu et al. (2004) investigated the determinants of exploration orientation in form of multidimensional qualitative assessments of "environmental dynamism", "organization mission", strategic orientation", "technology inflexibility", "environment-monitoring resources" and firm size. The study was based on data for 155 firms of the Dutch metal and engineering sector. The authors found positive effects for all factors just mentioned above with the exception of firm size and "technological inflexibility".

Lavie and Rosenkopf (2006) studied the determinants of 19'928 exploration-oriented alliances between 8,469 partners in the period 1990-2001. The authors found positive effects

for prior partnering experience and firm profitability, but no effects for R&D intensity, firm size, firm age and firm solvency.

In a study for Japanese shipbuilding firms based on 4061 observations for the period 1972-2000 Greve (2007) found a positive non-linear effect for firm size for both exploration-oriented and exploitation-oriented innovations, but only for explorative innovation a negative non-linear effect for firm age.

Broström and McKelvey (2009) examined some determinants of exploration/exploitation with respect to cooperative projects with universities and research organizations for 425 Swedish manufacturing firms in 2007. The likelihood of "open-ended" (exploration-oriented) cooperation was positively correlated with the firm having explicitly a strategy of cooperation with universities, and the partner being domestic and a university (rather than a research organization). No effect could be found for patent applications and R&D. The likelihood of exploitation-oriented cooperation correlated negatively with the firm having R&D activities and positively with the partner being domestic.

Bierly et al. (2009) investigated the antecedents of exploration-oriented versus exploitation-oriented acquisition and application of external knowledge. The study was based on data for 180 U.S. firms and yielded some interesting findings. Technological capability (a variable that is quite similar to absorptive capacity) was positively related to exploitation but not exploration. This result is contrary to the findings for absorptive capacity in most other studies. Technological relatedness (a variable that measures the opposite of technological diversity) was negatively correlated with exploration. Firm size showed no effect.

Bishop et al. (2011) investigated the factors determining the likelihood of exploration, exploitation and the combination of both categories of activities with respect to cooperative projects with universities for 420 UK firms in 2004, respectively. Exploration was characterized by continuous R&D, the quality of university partners, and firms being part of larger entries. Exploitation was primarily driven by firm size; the R&D intensity, number of partnerships, and geographical distance between partners did not show any effects.

Due to heterogeneity as to definitions, definition and measurement of exploration/ exploitation, method, model specification and available data, it is difficult to detect common results in the reviewed studies. In sum, in the reviewed studies firm size shows positive (mostly for exploitation activities) or no effects, firm age a positive or negative effect for exploitation activities, and a negative effect or no effects for exploration.

2.2.2 Exploration/exploitation and performance

Rosenkopf and Nerkar (2001) examined the impact of four different types of exploratory activities (local; internal boundary-spanning; external boundary-spanning; and radical) on subsequent technological development in the U.S. optical disk industry based on 2'333 patents of 22 firms in the period 1971-1995. They found positive effects for external

boundary-spanning exploration (i.e., exploration beyond only organizational boundaries) and – even stronger – positive effects for radical exploration (i.e., exploration beyond both organizational boundaries and technological boundaries).

In a further study, Rothaermel (2001) studied the interfirm cooperation between incumbents and new entrants based on data for 889 strategic alliances between 32 large pharmaceutical firms and providers of biotechnology in the period 1975-1997. He found that incumbents that focus on exploiting complementary assets (of the new entrant) outperform in terms of new product development incumbents that focus on exploring the new technology.

Rothaermel and Deeds (2004) in a study for 325 U.S. Biotech firms analyzed the impact of exploration-oriented alliances and exploitation-oriented alliances on innovation performance. The findings showed a positive effect of exploration alliances on the number of products in development and a positive effect of exploitation alliances on the number of market products.

He and Wong (2004) investigated the effects of explorative and exploitative innovation strategy on innovation intensity and on sales growth for 206 manufacturing firms in Singapore and the State of Penang in Malaysia in 1999/2000. The results showed, first, comparable positive effects of both exploration and exploitation on product innovation intensity, but positive effects only of exploitation on process innovation intensity, which reflects more short-term efficiency gains. The interaction of explorative and exploitative innovations strategies yielded no significant effects on innovation performance. Second, both strategies showed no effect on average sales growth rate. A further interesting finding was that the interaction of explorative and exploitative innovations strategies correlated positively with sales growth.

Auh and Menguc (2005) analyzed the moderating role of competitive intensity on the impact of exploration and exploitation on short-term (profitability or return on assets) and long-term (market share growth or sales growth) economic performance for a sample of 104 U.S. firms. Direct short-term effects of exploration and exploitation were of comparable magnitude. Firms that emphasize exploitation may have faced declining short-term performance with increasing competitive intensity, while firms with exploratory orientation may have improved short-term performance with increasing competition. Direct long-term effects of exploration were significantly larger than short-term effects. Competitive intensity showed an enhancing effect only for exploitation as to long-term performance.

In a study of 462 European financial institutions based on data collected in the years 2002/2003 Jansen et al. (2006) found no significant direct effects of exploratory and exploitative innovation on financial performance, but a positive indirect impact of exploitation moderated by the intensity of competition.

Lin et al. (2007) examined the influence of the different character of exploration-oriented and exploitation-oriented strategic alliance formations on firms' performance. The findings based

on data for 95 U.S. firms in the period 1988-1995 showed that alliances with mixed character benefit primarily large firms, while the focused formation of either exploratory or exploitative alliances benefits small firms.

In a further study based on data for 155 firms of the Dutch metal and electrical sector Sidhu et al. (2007) found positive effects on innovation performance of a composite measure of exploitation/exploration for demand-side search, but not for supply-side search.

Quintana-Garcia and Benavides-Velasco (2008) examined the influence of technological diversification (measured by the Herfindahl-Index of diversification with respect to technical fields according to the international patent classification) on innovation performance measured also by patents and found that the effect on exploration-oriented patenting is positive and significantly stronger than the respective effect for exploitation-oriented patenting. For the empirical investigation they used a sample of 115 U.S. biotechnology firms for the period 1976-2002.

Uotila et al. (2008) investigated the impact of exploration/exploitation on the financial performance (Tobin's Q) of 279 U.S. manufacturing firms in the period 1989-2004. The authors found an inverted U-shaped relationship between the relative share of explorative orientation and financial performance.

Hoang and Rothaermel (2010) studied the impact on two performance measures ("drug approval" and "project termination") of exploration and exploitation for 43 global pharmaceutical firms between 1980 and 2000. The results showed positive effects for external (i.e. based on alliances with other firms) exploitation for both performance measures, a negative effect of external exploration for drug approval, and no effect for internal exploration and internal exploitation for both performance measures. In addition, the study found a positive interaction effect between internal exploration and external exploitation and a negative interaction term internal/exploration/external exploration for drug approval, but exactly the contrary effects with respect to sign for project termination.

In sum, in spite of the heterogeneity of the reviewed studies with respect to definition and measurement of exploration/exploitation, method, model specification and available data, there is a discernible tendency for exploitative activities to have a stronger impact on innovation and economic performance, at least on the short-run. There is also some scarce evidence that exploration outperforms exploitation with respect to both innovation performance and economic performance in the long-run.

2.3 Research hypotheses

Based on the discussion of theoretical and empirical literature we posited a series of research hypotheses concerning (a) the determinants of explorative versus exploitative activities in cooperation with universities and (b) the impact of such activities on innovation performance:

Hypothesis 1: A firm's knowledge absorptive capacity is stronger positively correlated with the likelihood of explorative activities than the likelihood of exploitative activities.

Hypothesis 2: The degree of technological diversification of a firm is positively correlated with the likelihood of explorative, but negatively with the likelihood of exploitative activities.

Hypothesis 3: The intensity of price competition on the product market is positively correlated with the likelihood of exploitative activities, while non-price competition is positively correlated with the likelihood of explorative activities.

Hypothesis 3a: Market concentration favours exploitation activities.

Hypothesis 4: Firm size is stronger positively correlated with the likelihood of explorative activities than with the likelihood of exploitative activities.

Hypothesis 5: Firm age is correlated with the likelihood of explorative activities with ambiguity and it is positively correlated with the likelihood of exploitative activities.

Hypothesis 6: Exploitation-oriented activities are stronger positively correlated with innovation performance than exploration-oriented activities.

3. Model specification

3.1 Drivers of exploitation versus exploration

3.1.1 Dependent variable

Our questionnaire (see data section) contains one question on the *specific nature* of the R&D projects that were realized in cooperation with universities or other research organizations, which allows us to operationalize the "exploration versus exploitation" concept and to investigate whether there are differences with respect to the characteristics of firms pursuing the one or the other strategy:

Question 6.1:
"The knowledge exchange with universities has brought out:
(a) the initiation of new R&D projects: yes/no;
(b1) the development of new products: yes/no;
(b2) the development of new processes: yes/no".

Firms that reported that an outcome of their KTT (knowledge and technology transfer) activities with universities was the initiation of new R&D projects are considered to pursue an "exploration" strategy aiming at an expansion of their knowledge base in the direction of new technologies. Firms that reported the development of new products and or new processes as the main outcome of KTT activities are seen to pursue a strategy of further "exploitation" of an already existing knowledge base. Of course, there are also firms that reported both strategies.

As *dependent* variable served a nominal variable that takes the following four values referring to mutually exclusive groups of firms (variable EXPL; see Table 1).[3]

0: firms without KTT activities;

1: firms with KTT activities but without exploration or exploitation (reporting 'no' for both relevant questions; see footnote 3);

2: "exploration": firms responding *'yes' to question (a)* above and answering whatever to questions (b1) and (b2), effectively "hybrid" firms ('exploration');

3: "exploitation": firms responding *'no' to question (a)* above and answering 'yes' to either question (b1) or (b2) or both of them ('exploitation').

Table 2 shows the composition of the dataset with respect to the four main groups of forms that were distinguished in our model.

3.1.2 Independent variables

The relevant characteristics of the firms that according to literature would be related to a firm's inclination to pursue the one or the other strategy are reflected in the choice of the independent variables. As *independent* variables we considered (a) variables that describe a firm's resource endowment as well as its knowledge absorptive capacity (Cohen and Levinthal 1990): human capital intensity (HQUAL); existence of a R&D department; R&D cooperation (R&D_COOP); and intensity of physical capital (LCL); (b) variables indicating the technological fields in which firms are active (dummy variables for 13 technological fields (see Table 3; model 1) or (alternatively) the technological diversification of firms, measured by the *number* of technological fields, in which a firm is active (TECH_DIV; model 2);[4] (c) variables characterizing the market environment of firms (variable for the intensity of price competition (IPC), intensity of non-price competition (INPC) and the number of principal competitors in the main product marker (NCOMP)); and (d) a series of control variables such as firm size (LEMPL); firm age (FAGE); foreign-owned (FOREIGN) and sub-sectors dummy variables.

Expected were stronger positive effects for the exploration-oriented firms as compared with the exploitation-oriented firms for the variables reflecting absorptive capacity (Hypothesis 1) and for the technological diversification variable (Hypothesis 2). Further, price competition was not expected to be relevant for exploration-oriented firms but rather non-price competition (Hypothesis 3). Higher market concentration would be more favourable for exploration than for exploitation (Hypothesis 3a). As to firm size (Hypothesis 4) and firm age

[3] The rather low number of observations did not allow the construction of a 'pure' category "exploration".
[4] We also include a dummy variable (TECH) for firms that reported at least one technological field, in which they were active, as control variable because about 40% of the firms in our sample were not active in any technological field.

(Hypothesis 5) we expected positive effects. With respect to foreign affiliation we had no a priori expectations.

3.2 Impact on innovation performance

We specified an innovation equation that contained the same right-hand variables as the exploration/exploitation equation in 3.1. As dependent variable served the sales share of innovative products (new products and considerably modified products). For each of the levels 1, 2, and 3 of the nominal variable EXPL we constructed a binary variable. The three binary variables EXP1, EXP2 and EXP3 were inserted as additional right-hand variables in the innovation equation (see Table 1). Thus, the group of firms without KTT activities (EXP0) is the reference group. We expect a stronger effect on innovation performance of the exploitation variable (Hypothesis 6).

4. Data

The data used in this study were collected in spring 2011 in the course of a specific survey on KTT among Swiss enterprises using a questionnaire, which contained questions on the incidence of KTT activities among firms, forms, channels, motives and impediments of the KTT activities of Swiss firms as well on some basic firm characteristics (innovation and R&D activities, investment, sales, exports, employment and employees' vocational education.[5] The survey was based on a (with respect to firm size) disproportionately stratified random sample of firms with at least 5 employees covering all relevant industries of the manufacturing sector, the construction sector and selected service industries as well as firm size classes (on the whole 25 industries and within each industry three industry-specific firm size classes with full coverage of the upper class of large firms). Answers were received from 1841 firms, i.e. 40% of the firms in the underlying sample. The response rates do not vary much across industries and size classes with a few exceptions. There was an over-representation of plastics/rubber and energy/water and an under-representation of clothing/leather, telecommunication, vehicles and glass/stone clay. A careful examination of the data of these 1841 firms led to the exclusion of 113 cases with contradictory or non-plausible answers; there remained 1728 valid answers which were used for this analysis. Descriptive statistics and correlations of the variables that were used in the econometric part are found in Table A.1 and Table A.2 in the Appendix, respectively.

[5] Versions of the questionnaire in German, French and Italian are available at www.kof.ethz.ch.

5. Empirical results

5.1 Econometric issues

Drivers of exploitation versus exploration

Given the character of the dependent variable multinomial probit estimation would be the appropriate econometric method to be applied. This allows the comparison as to the relevance of right-hand variables between the exploration-focussed and the exploitation-focused firms.

Since the results are only cross-section estimates, it is not possible to test directly the existence of causal relations between the independent variables and the dependent variable. Moreover, it is difficult to find valid instruments in our sample for so many variables. Nevertheless, some robust regularities emerge, which, if interpreted in view of our main hypothesis, could indicate the direction of causal links.

Impact on innovation performance

The problem of possible endogeneity of the variables for exploration and exploitation is accentuated if we want to test the influence of these variables on innovation performance. In order to test for endogeneity we needed valid instruments. We found three valid instruments, two (OBSTACLE2, OBSTACLE3; see Table 1) refer to characteristics of the science partner which are clearly exogenous and not susceptible from the view of the firm, i.e. 'Firms' R&D questions are not interesting for science partners' and 'lack of personnel for KTT on the part of potential science partners'. A third instrument (OBSTACLE1) identifies the 'lack of interest for scientific projects'. Also this instrument cannot be influenced by the firm at least in the short run. Of course, in the long run a firm can change or essentially modify its knowledge base and develop an interest for scientific projects. However, this is very difficult and expensive (see Teece et al. 1997)[6]. Moreover, the instruments passed all three statistical criteria for validity: significant correlation to the instrumented variables, insignificant correlation to the dependent variables and insignificant correlation to the error term of the innovation equation. We tested endogeneity by applying the procedure by Rivers and Vuong (1988). Instrument equations were estimated separately for each of the relevant right-hand variables already mentioned above for all innovation indicators and for each country. The residuals (predicted instrumented variables minus original variable) of the first stage instrument equations were inserted in the innovation equation as additional right-hand variables. Bootstrapping was used in order to correct the standard errors of the estimated parameters. If the coefficient of the residuals was statistically significant (at the 10%-test level), we have assumed that endogeneity is a problem and consequently based our inference on instrumented variables; also in this case standard errors were estimated by bootstrapping.

[6] Teece et al. (1997) mention several reasons for the persistence of the knowledge base: firms lack the organizational capacity to develop new competences (or interest for scientific questions), some assets are not tradable (e.g., tacit knowledge), and needed inputs have to be bought at relatively high prices that reduce possible rents.

In cases in which the coefficient of the residual was not statistically significant, we have assumed exogeneity of the outsourcing variables and the estimates were based on the original variables. We tested endogeneity in separate estimates for each of the three variables EXP1, EXP2 and EXP3 and found no evidence that endogeneity could be a problem (see Table A.3 in the appendix). We used a Tobit model in order to cope with the problem that many firms have null sales of innovative products.

5.2 Exploration versus exploitation

Table 3 shows the multinomial probit estimates for the model that was outlined above. As reference group was used the exploitation group, so that we can directly compare the relative importance of the various determining factors for the two relevant categories (exploration firms versus exploitation firms).

We obtained a clear pattern of the differences between 'exploration'-oriented and 'exploitation'-oriented firms (columns 3 and 6 in Table 3). Firms with a focus on exploration showed a significantly higher knowledge absorptive capacity (positive effects of the variables for human capital intensity, R&D cooperation and the existence of a R&D department) than firms that concentrate in exploitation. Hence, Hypothesis 1 received empirical support. No difference could be found with respect to physical capital intensity. A positive effect for R&D intensity only for exploration-oriented firms was also found by Bishop et al. (2011). Lavie and Rosenkopf (2006) and Broström and McKelvey (2006) could not find a statistically significant effect of R&D intensity for exploratory activities.[7]

Exploration-oriented firms did not focus on any particular type of technology (with the exception of *nanotechnology*) as compared to exploitation-oriented firms (model 1), but they showed a significantly higher degree of technological diversification (in terms of the number of technological fields, in which they are active) than exploitation-oriented firms (model 2). This was a hint in favour of Hypothesis 2. A similar effect was found by Sidhu et al. (2004) for "technological inflexibility", which we interpret as some kind of measure for technological diversity, Quintana-Garcia and Benavides-Velasco (2008) for technological diversification, and Bierly et al. (2009) for "technological relatedness" (a measure that we interpret as the opposite of diversity).

Larger firms appeared to be stronger inclined to exploration than smaller ones. This result is in accordance with Hypothesis 4. However, the size effect is only significant in model 2. The results of other similar studies are mixed.

The firm age effect is contrary to our Hypothesis 5 (significantly positive in model 1, insignificant in model 2). Older firms seemed to invest more in exploitation activities even if they might have strong invested interests in existing knowledge, presumably because their

[7] However, Bierly et al. (2009) found a positive correlation for their measure of absorptive capacity ("technological capability") only for exploitation.

financial means allow them to pursue better a strategy of technological diversification than younger ones. No firm age effect could be found for explorative activities in the study of Lavie and Rosenkopf (2006). A negative effect in line with Hypothesis 5 was found only in Greve (2007).

As expected according to Hypothesis 3, price competition was more relevant for exploitation-oriented firms. No difference could be found with respect to non-price competition and the number of competitors (proxy for market concentration). Thus, Hypothesis 3a was not confirmed and Hypothesis 3 only partly. To our knowledge, no other similar studies consider competition as a determining factor, so we cannot compare with the results of other studies.

The estimates show also that there were practically no differences between firms that reported neither exploitation nor exploration activities and those that are exploitation-oriented (columns 2 and 5, respectively in Table 3); only the variable for technological diversification is significant and indicates that exploitation-oriented firms have a broader technological portfolio than firms without exploration or exploitation activities. Further, firms without KTT activities of any kind are on average smaller, had clearly a significantly lower absorptive capacity, are more likely to be found among foreign firms than firms with KTT activities (with or without exploration/ exploitation activities; columns 1 and 4 in Table 3). This is a further interesting result that highlights the different profiles of firms with and firms without KTT activities.

5.3 Impact on innovation performance

The estimates of the innovation performance equation are presented in Table 4. Positive and statistically significant are only the dummy variable for exploitation-oriented firms and the one for firms without exploitation or exploration activities, but not that for exploration-oriented activities.[8] This finding is in accordance with hypothesis 6 and most of the empirical literature reviewed in section 2.2.2. It is remarkable that in our case we found a lower innovation performance not just for firms that are exclusively focussed on explorative activities but for firms that report explorative activities *besides* exploitation for new product and/or processes. This can be interpreted as a hint that explorative activities require a substantial share of resources that cannot be dedicated to the exploitation of existing knowledge; in a way, this is a kind of crowding out of short- and medium-term investment in innovation. In management and organization literature there is a debate on the nature of the

[8] The robustness of this result was tested by additional estimates not shown here, in which eight dummy variables for all feasible cases in our sample (instead of EXP1, EXP2 and EXP3) were inserted in the estimation equation: (1) no exploitation/exploration; (2) exploitation/only new products; (3) exploitation/only new processes; (4) exploitation/new products+new processes; (5) only exploration; (6) exploration/exploitation/only new products; (7) exploration/exploitation/only new processes; and (8) exploration/exploitation/new products+ new processes (see Table 2). We obtained significantly positive marginal effects only for the dummy variables for (1), (2) and (3).

relationship between exploration and exploitation activities (substitutive or complementary) and the implications of the kind of relationship for firms' investment strategy (see, e.g., He and Wong 2004; Gupta et al. 2006; and Chen and Katila 2008). Our results seem to provide evidence in favour of the substitutive relationship.

Our estimates yielded some additional interesting results. As expected the variables for absorptive capacity are positively correlated with the sales share of innovative products. Larger and/or older firms seem to have larger sales shares of innovative products than smaller and/or younger firms. Competition pressure is also positively correlated with high sales shares of innovative products. New materials, software, medical technology, environmental technologies and computed-integrated manufacturing technologies appear to be fields of activities with relatively higher sales shares of innovative products. A further interesting result was the positive effect of technological diversification (model 2). A broad portfolio of technological activities seems to enhance innovation performance, a finding that is not in accordance with a considerable part of existing empirical evidence.[9]

6. Summary and conclusions

In a first step, we developed based on existing theoretical and empirical literature a series of hypotheses with respect to the relative importance of possible determinants of exploration and exploitation activities and tested them on Swiss firm data. In a second step, we investigated the impact on innovation performance of knowledge exploration versus knowledge exploitation. This integrated framework for the investigation of both determinants of exploration activities versus exploitation activities and the impact of both of them on innovation performance is a central characteristic of this paper that distinguishes it from existing literature.

We obtained a clear pattern of the differences between 'exploration'-oriented and 'exploitation'-oriented firms. Firms with a focus on exploration showed a significantly higher knowledge absorptive capacity than firms that concentrate in exploitation. Exploration-oriented firms did not focus on any particular type of technology (with the exception of *nanotechnology*) as compared with exploitation-oriented firms, but they showed a significantly higher degree of technological diversification (in terms of the number of technological fields, in which they are active) than exploitation-oriented firms. Larger and/or older firms appeared to be stronger inclined to exploration than smaller and/or younger ones; these are rather weak effects. Price competition was more relevant for exploitation-oriented

[9] Woerter (2009) found for Swiss firms a positive effect of a patent-based measure of technological specialization – which is different from the applied one in the paper at hand - on the sales shares of innovative products. Also Bolli and Woerter (2012) found for R&D-active manufacturing firms that technological specialization is positively related with the sales share of new innovative products.

firms. No difference could be found with respect to non-price competition and the number of principal competitors in a firm's main sales market (proxy for market concentration).

Further, we found a positive effect on innovation performance for exploitation-oriented firms but not for those that were exploration-oriented. Given the fact that exploration-oriented firms in our study were to a large extent part also exploitation-oriented this finding can be interpreted as a hint that explorative activities require a substantial share of resources that cannot be dedicated to the exploitation of existing knowledge; in a way, this is a kind of crowding out of short- and medium-term investments in innovation.

In sum, the Hypotheses 1 (absorptive capacity), 2 (technological diversification), partly 3 (competition), 4 (firm size) and 6 (exploitation correlates positively with innovation performance) received supportive evidence. This was not the case for Hypothesis 5 (firm age) and Hypothesis 3a (market concentration).

Do the differences between exploration- and exploitation-oriented firms that we found in this study matter for economic policy? If the firm profiles for these two types of knowledge acquisition activities are discernibly different as we showed on this study, the promotion of knowledge and transfer activities between different categories of firms and different categories of universities can be specifically targeted, for example, by Technology Transfer Offices or other Government Agencies that undertake mediation and coordination functions between business partners and science partners. This would increase the efficiency of policy.

References

Arvanitis, S., Kubli, U. and M. Woerter (2011): Knowledge and Technology Transfer Activities between Firms and Universities in Switzerland: An Analysis Based on Firm Data, *Industry and Innovation*, 18(4), 369-392.

Arvanitis, S., Sydow, N. and M. Woerter (2008): Is There Any Impact of University-Industry Knowledge Transfer on Innovation and Productivity? – An Empirical Analysis Based on Swiss Firm Data, *Review of Industrial Organization*, 32, 77-94.

Arvanitis, S. and M. Woerter (2009): Firms' Strategies for Knowledge and Technology Transfer with Public Research Organisations and their Impact on Firms' Performance, *Corporate and Industrial Change*, 18(6), 1067-1106.

Arthur, B. (1989): Competing Technologies, Increasing Returns, and Lock-in by Historical Events, *Economic Journal*, 99(394), 116-131

Auh, S. and B. Menguc (2005): Balancing Exploration and Exploitation: The Moderating Role of Competitive Intensity, *Journal of Business Research*, 58(12), 1652-1661.

Bierly III, P.E., Damanpour, F. and M.D. Santoro (2009): The Application of External Knowledge: Organizational Conditions for Exploration and Exploitation, *Journal of Management Studies*, 456(3), 481-509.

Bishop, K., D'Este, P. and A. Nelly (2011): Gaining from Interactions with Universities: Multiple Methods for Nurturing Absorptive Capacity, *Research Policy*, 40, 30-40.

Bolli, T., Woerter, M. (2012): Technological Innovation and Innovation Performance, mimeo. Zurich.

Broström, A. and M. McKelvey (2009): How Do Organizational and Cognitive Distances Shape Firms' Interactions with Universities and Public Research Institutes?, *CESIS Electronic Working Paper Series, Paper No. 188*, The Royal Institute of Technology, Stockholm (http://www.cesi.se).

Chen, E.L. and R. Katila (2008): Rival Interpretations of Balancing Exploration and Exploitation: Simultaneous or Sequential?, in S. Shane (ed.), *Handbook of Technology and Innovation Management*, John Wiley, London, pp.197-214.

Cohen, W.M. and D.A. Levinthal (1989): Innovation and Learning: The Two Faces of R&D, *Economic Journal*, 9, 569-596.

Cohen, W.M. and D.A. Levinthal (1990): Absorptive Capacity: A New Perspective on Learning and Innovation, *Administrative Science Quarterly*, 35, 128-152.

Cohen, W.M., Nelson, R.R. and J.P. Walsh (2002): Links and Impasses: The Influence of Public Research on Industrial R&D; *Management Science*, 48(1), 1-23.

Greve, H.R. (2007): Exploration and Exploitation in Product Innovation, *Industrial and Corporate Change*, 16(5), 945-975.

Gupta, A.K., Smith, K.G. and C.E. Shalley (2006): The Interplay between Exploration and Exploitation, *Academy of Management Journal*, 40(4), 693-706.

Hall, B. H. (1992): Research and Development at the Firm Level: Does the Source of Financing Matter? National Bureau of Business Research, Working Paper No. 4096.

He, Z.L. and P.K. Wong (2004): Exploration vs. Exploitation: An Empirical Test of the Ambidexterity Hypothesis, *Organization Science*, 15(4), 481-494.

Hoang, H. and F.T. Rothaermel (2010): Leveraging Internal and External Experience: Exploration, Exploitation, and R&D Project Performance, *Strategic Management Journal*, 31, 734-758.

Jansen, J.J.P., Van den Bosch, F.A.J. and H.W. Volberba (2006): Exploratory Innovation, Exploitative Innovation, and Performance: The Impact of Organizational Antecedents and Environmental Moderators, *Management Science*, 52(11), 1661-1674.

Lavie, D. and L. Rosenkopf (2006): Balancing Exploration and Exploitation in Alliance Formation, *Academy of Management Journal*, 49(4), 797-818.

Lavie, D, Stettner, U. and M.L. Tushman (2010): Exploration and Exploitation within and across Organizations, *Academy of Management Annals*, 4(1), 109-155.

Levinthal, D.A. and J.G. March (1981): A Model of Adaptive Organizational Search, *Journal of Economic Behavior and Organization*, 2, 307-333.

Levinthal, D.A. and J.G. March (1993): The Myopia of Learning, *Strategic Management Journal*, 14, 95-112.

Li, Y., Vanhaverbeke, W. and W. Schoenmakers (2008): Exploration and Exploitation n Innovation: Reframing the Interpretation, *Creativity and Innovation Management*, 17(2), 107-126.

Lichtenthaler, U. and E. Lichtenthaler (2009): A Capability-based Framework for Open Innovation: Complementing Absorptive Capacity, *Journal of Management Studies*, 46(8), 1315-1338.

Lin, Z.J., Yang, H. and I. Demirkan (2008): The Performance Consequences of Ambidexterity in Strategic Alliance Formations: Empirical Investigation and Computational Theorizing, *Management Science*, 53(10), 1645-1658.

March, J.G. (1991): Exploration and Exploitation, *Organization Science*, Special Issue: Organizational Learning: Papers in Honor of (and by) James G. March, 2(1), 71-87.

Quintana-Garcia, C. and C.A. Benavides-Velasco (2008): Innovative Competence, Exploration and Exploitation: The Influence of Technological Diversification, *Research Policy*, 37, 492-507.

Rivers, D. and Q.H. Vuong (1988): Limited Information Estimators and Exogeneity Tests for Simultaneous Probit Models, *Journal of Econometrics*, 39, 347-366.

Rosenkopf, L. and A. Nerkar (2001): Beyond Local Search: Boundary-spanning, Exploration, and Impact in the Optical Disc Industry, *Strategic Management Journal*, 22(4), 287-306.

Rothaermel, F.T. (2001): Incumbent's Advantage through Exploiting Complementary Assets via Interfirm Cooperation, *Strategic Management Journal*, 22, 687-699.

Rothaermel, F.T. and D.L. Deeds (2004): Exploration and Exploitation Alliances in Biotechnology: A System of New Product Development, *Strategic Management Journal*, 25(3), 201-221.

Sidhu, J.S., Commandeur, H.R. and H.W. Volberda (2007): The Multifaceted Nature of Exploration and Exploitation: Value of Supply, Demand, and Spatial Search for Innovation, *Organization Science*, 18(1), 20-38.

Sidhu, J.S., Volberda, H.W. and H.R. Commandeur (2004): Exploring Exploration Orientation and Its Determinants,: Some Empirical Evidence, *Journal of Management Studies*, 41(6),813-932.

Teece, D.J., G. Pisano and A. Schuen (1997): Dynamic Capabilities and Strategic Management, *Strategic Management Journal*, 18(7), 507-533.

Uotila, H., Maula, M., Keil, T. and Zahra, S.A. (2008): Exploration, Exploitation, and Financial Performance: Analysis of S&P 500 Corporations, *Strategic Management Journal*, 30, 221-231.

Winter, S.G. (1971): Satisficing, Selection, and the Innovating Remnant, *Quarterly Journal of Economics*, 85, 237-261.

Woerter, M. (2009): Technology Diversification, Product Innovations, and Technology Transfer, *KOF Working Paper No. 221*, Zurich.

Zollo, M. and S.G. Winter (2002): Deliberate Learning and the Evolution of Dynamic Capabilities, *Organization Science*, 13(3), 339-351.

Tables:

Table 1: Definition of variables

Variable	Definition
Dependent variables	
Probit estimates	
EXPL	Nominal variable: 0: firms without KTT; 1: firms with KTT, but neither 'exploration' nor 'exploitation'; 2: firms with 'exploration', i.e. firms that reported that KTT led to the initiation of new R&D projects, either exclusively or in combination with the development of new products and/or new processes 3: firms with 'exploitation', i.e. firms that reported that KTT helped to develop new products and/or new processes, but *not* to the initiation of new R&D projects
Multinomial probit estimates	
LINNL	Natural logarithm of the sales share of innovative products (new *and* considerably modified products)
LIMPS	Natural logarithm of the sales share of *considerably modified* products
LNEWS	Natural logarithm of the sales share of *new* products
Independent variables	
LINVEST/L	Natural logarithm of gross investment per employee
LHQUAL	Natural logarithm of the share of employees with tertiary-level formal education
R&D_DEPARTMENT	Binary variable (yes/no)
R&D_COOP	Binary variable: R&D cooperation (yes/no)
IPC	Intensity of price competition; five-level ordinal variable (level 1: 'very weak'; level 5 'very strong')
INPC	Intensity of non-price competition; five-level ordinal variable (level 1: 'very weak'; level 5 'very strong')
NCOMP	Interval variable: up to 5 competitors; 6 to 10; 11 to 15; 16 to 50; more than 50
LEMPL	Natural logarithm of the number of employees (in full-time equivalents)
LAGE	Natural logarithm of firm age [2011-(year, in which a firm was founded)]
FOREIGN	Binary variable: foreign-owned firm (yes/no)
Technologies	Binary variables (yes/no)
TECH	Binary variable: firms with at least 1 technology field, in which they are active
TECH_DIV	Technological diversification: number of technologies, in which a firm is engaged in its activities
EXP1	Binary variable: firms with KTT, but neither 'exploration' nor 'exploitation'
EXP2	Binary variable: firms with 'exploration', i.e. firms that reported that KTT led to the initiation of new R&D projects, either exclusively or in combination with the development of new products and/or new

	processes
EXP3	Binary variable: firms with ‘exploitation’, i.e. firms that reported that reported that KTT helped to develop new products and/or new processes, but *not* to the initiation of new R&D projects
Instruments	
OBSTACLE1	“Lack of interest for scientific projects”; five-level ordinal variable (level 1: 'not important'; level 5 'very important')
OBSTACLE2	“Firms’ R&D questions are not interesting for science partners”; five-level ordinal variable (level 1: 'not important'; level 5 'very important')
OBSTACLE3	“Lack of personnel for KTT on the part of potential science partners”; five-level ordinal variable (level 1: 'not important'; level 5 'very important')
The metric variables refer to the year 2010.	

Table 2: Exploration vs. exploitation: Composition of the dataset

Variable	Definition	N	%
EXPL = 0	Firms without KTT	*1232*	71.3
EXPL = 1	Firms with KTT, but neither 'exploration' nor 'exploitation'	*140*	8.1
EXPL = 2	'Exploration'	*173*	10.0
	Firms with 'exploration' only	28	
	Firms with 'exploration' + R&D projects that helped to develop new products	53	
	Firms with 'exploration' + R&D projects that helped to develop new processes	18	
	Firms with 'exploration' + R&D projects that helped to develop new products and new processes	74	
EXPL = 3	'Exploitation'	*183*	10.6
	firms with 'exploitation' that led to new products	60	
	firms with 'exploitation' that led to new processes	75	
	firms with 'exploitation' that led to new products and new processes	48	

Table 3: Multinomial probit estimates; variable EXPL (0: no KTT; 1: neither 'exploration' nor 'exploitation'; 2: 'exploration'; 3: 'exploitation')

	Model 1			Model 2		
	EXPL = 0	EXPL = 1	EXPL = 2	EXPL = 0	EXPL = 1	EXPL = 2
LINVEST/L	-0.051	0.007	0.063	-0.068*	-0.003	0.073
	(0.037)	(0.049)	(0.062)	(0.038)	(0.045)	(0.063)
LHQUAL	-0.231***	0.066	0.297**	-0.227***	0.059	0.283**
	(0.077)	(0.101)	(0.123)	(0.073)	(0.094)	(0.127)
R&D_DEPARTMENT	-0.473***	-0.082	0.476**	-0.476***	-0.011	0.421**
	(0.169)	(0.206)	(0.213)	(0.169)	(0.200)	(0.217)
R&D_COOP	-0.907***	-0.167	0.561***	-1.015***	-0.163	0.579***
	(0.179)	(0.205)	(0.197)	(0.176)	(0.201)	(0.190)
TECH				-0.456***	0.028	-0.263
				(0.176)	(0.217)	(0.250)
TECH_DIV				-0.068	-0.105**	0.107**
				(0.042)	(0.053)	(0.045)
Technology:						
Nanotechnology	0.227	-0.323	1.307***			
	(0.407)	(0.539)	(0.382)			
New materials	-0.409***	-0.260	-0.250			
	(0.157)	(0.193)	(0.198)			
Microelectronics	0.307	0.387	-0.205			
	(0.267)	(0.300)	(0.300)			
Laser technology/	-0.333	-0.284	-0.060			
optoelectronics	(0.272)	(0.327)	(0.307)			
Software / simulation /	-0.328**	0.009	0.083			
artificial intelligence	(0.162)	(0.195)	(0.200)			
Telecommunication /	0.246	-0.213	0.131			
Information technology	(0.189)	(0.238)	(0.232)			
Gene / biotechnology	-0.805	-0.039	0.201			
	(0.511)	(0.527)	(0.492)			
Medical technology	-0.099	0.221	0.146			
	(0.229)	(0.265)	(0.265)			
Computer-integrated	-0.003	-0.170	0.252			
manufacturing technology	(0.185)	(0.231)	(0.220)			
Transport technology	-0.053	-0.298	0.169			
	(0.183)	(0.241)	(0.229)			
Energy technologies	-0.376**	-0.041	-0.124			
	(0.193)	(0.237)	(0.241)			
Environm. technologies	-0.217	-0.042	-0.010			
	(0.169)	(0.209)	(0.215)			
Geological technologies	-1.010*	-0.816	-0.120			
	(0.543)	(0.701)	(0.570)			
LEMPL	-0.217***	0.009	0.095	-0.210***	0.004	0.124*
	(0.048)	(0.060)	(0.062)	(0.049)	(0.056)	(0.067)
LAGE	-0.024	0.061	0.192*	-0.124	0.040	0.148
	(0.085)	(0.107)	(0.116)	(0.089)	(0.105)	(0.115)
FOREIGN	0.319*	0.324	-0.202	0.350**	0.364*	-0.121
	(0.175)	(0.205)	(0.228)	(0.179)	(0.204)	(0.222)
IPC	-0.013	-0.008	-0.176**	0.003	0.001	-0.182**

	(0.068)	(0.084)	(0.089)	(0.067)	(0.082)	(0.093)
INPC	-0.037	-0.029	0.121	-0.051	-0.043	0.102
	(0.071)	(0.088)	(0.098)	(0.070)	(0.089)	(0.098)
NCOMP	-0.015	-0.077	-0.096	-0.015	-0.068	-0.097
	(0.047)	(0.060)	(0.068)	(0.047)	(0.060)	(0.066)
Const.	4.930***	0.114	-2.545**	5.054***	-0.825	-2.514***
	(0.681)	(0.868)	(1.043)	(0.727)	(0.990)	(1.113)
N		1728			1728	
Wald chi2		479.5			16223.8	
Prob > chi2		0.000			0.000	

Note: Reference group: EXPL = 3 ('exploitation'); see Table 1 for the definition of EXPL. ***, ** and * denote statistical significance at the 1%, 5% and 10% test level respectively. Model 1 includes sector controls; model 2 includes 2-digit industry controls.

Table 4: Tobit estimates; variable LINNS; marginal effects

	LINNS Model 1	LINNS Model 2
EXP1 ('neither nor')	0.298**	0.254*
	(0.152)	(0.136)
EXP2 (exploration)	0.136	0.137
	(0.154)	(0.143)
EXP3 (exploitation)	0.426***	0.373***
	(0.139)	(0.120)
LINVEST/L	0.023	0.026
	(0.019	(0.019)
LHQUAL	0.150***	0.166***
	(0.040	(0.040)
R&D_DEPARTMENT	0.830***	0.635***
	(0.130)	(0.106)
R&D_COOP	0.198	0.234**
	(0.126)	(0.116)
TECH		0.681***
		(0.101)
TECH_DIV		0.091***
		(0.026)
Technology:		
Nanotechnology	0.098	
	(0.224)	
New materials	0.417***	
	(0.107)	
Microelectronics	0.068	
	(0.161)	
Laser technology/	0.278	
optoelectronics	(0.181)	
Software / simulation /	0.506***	
artificial intelligence	(0.113)	
Telecommunication /	0.235**	
information technology	(0.120)	
Gene / biotechnology	-0.034	
	(0.287)	
Medical technology	0.251*	
	(0.151)	
Computer-integrated	0.330***	
manufacturing technology	(0.124)	
Transport technology	0.133	
	(0.111)	
Energy technologies	-0.280***	
	(0.109)	
Environm. technologies	0.206*	
	(0.109)	
Geological technologies	0.097	
	(0.356)	
LEMPL	0.082***	0.085***
	(0.029)	(0.029)

LAGE	-0.089*	-0.002
	(0.049)	(0.001)
FOREIGN	0.042	-0.050
	(0.101)	(0.100)
IPC	0.098***	0.066*
	(0.040)	(0.040)
INPC	0.139***	0.128***
	(0.042)	(0.041)
NCOMP	-0.033	-0.030
	(0.028)	(0.028)
Const.	-4.403***	-3.214***
	(0.667)	(0.624)
N	1717	1717
N left-censored	885	885
Pseudo R2	0.120	0.123
LR chi2	669.3	684.5
Prob > chi2	0.000	0.000

Note: Reference group: firms without KTT; see Table 1 for the definition of EXP1, EXP2 and EXP3; ***, ** and * denote statistical significance at the 1%, 5% and 10% test level respectively. Model 1 includes sector controls; model 2 includes 2-digit industry controls.

APPENDIX:

Table A.1: Descriptive statistics

	Mean (N=1728)	Standard deviation
LINNS	1.553	1.704
LINVEST/L	8.661	2.178
LQUAL	2.730	1.075
R&D department	0.235	0.424
R&D_COOP	0.149	0.356
IPC	3.920	0.953
INPC	3.224	0.900
NCOMP	2.594	1.398
TECH_DIV	1.463	1.804
LEMPL	4.204	1.471
LAGE	3.887	0.776
FOREIGN	0.169	0.375
EXP1	0.081	0.265
EXP2	0.100	0.292
EXP3	0.106	0.299

Table A.2: Independent variables: correlation matrix

	LINVEST/L	LQUAL	R&D depart.	R&D_ COOP	LEMPL	IPC	INPC	NCOMP	LAGE	FOREIGN	TECH_ DIV	EXP1	EXP2
LINVEST/L	1.000												
LQUAL	0.051	1.000											
R&D depart.	0.114	0.220	1.000										
R&D_COOP	0.103	0.180	0.506	1.000									
LEMPL	0.237	0.119	0.292	0.245	1.000								
IPC	-0.037	-0.008	-0.002	-0.019	0.054	1.000							
INPC	0.037	0.109	0.165	0.117	0.092	0.052	1.000						
NCOMP	-0.047	-0.041	-0.152	-0.145	-0.138	0.134	-0.036	1.000					
LAGE	0.125	-0.027	-0.001	0.023	0.213	0.065	-0.004	-0.027	1.000				
FOREIGN	-0.077	0.131	0.125	0.059	0.168	0.017	0.092	-0.126	-0.117	1.000			
TECH_DIV	0.153	0.140	0.322	0.292	0.252	0.026	0.099	-0.032	0.063	0.049	1.000		
EXP1	0.042	0.110	0.124	0.092	0.097	0.008	0.025	-0.053	0.019	0.065	0.040	1.000	
EXP2	0.104	0.177	0.367	0.436	0.254	-0.045	0.107	-0.105	0.054	0.016	0.298	-0.088	1000
EXP3	0.068	0.090	0.160	0.154	0.111	0.021	0.038	-0.008	0.025	-0.008	0.142	-0.095	-0.104

Table A.3: First stage equations and Rivers-Vuong-test for endogeneity

	EXP1	EXP2	EXP3	LINNS	LINNS	LINNS
OBSTACLE3	-0.407**					
	(0.201)					
OBSTACLE2		-0.635***				
		(0.146)				
OBSTACLE1			-0.372***			
			(0.123)			
EXP1				0.225	0.559***	0.536***
				(0.567)	(0.244)	(0.209)
RES1_OBSTACLE3				0.333		
				(0.552)		
EXP2				0.296	0.101	0.266
				(0.211)	(0.273)	(0.234)
RES2_OBSTACLE2					0.221	
					(0.243)	
EXP3				0.762***	0.787***	0.974***
				(0.210)	(0.214)	(0.470)
RES3_OBSTACLE1						-0.241
						(0.466)
LINVEST/L	0.037*	0.065*	0.036	0.042	0.051	0.027
	(0.022)	(0.037)	(0.023)	(0.043)	(0.043)	(0.043)
LHQUAL	0.167***	0.319***	0.110**	0.316***	0.329**	0.234**
	(0.054)	(0.089)	(0.048)	(0.120)	(0.115)	(0.104)
R&D department	0.101	0.628***	0.152	1.406***	1.505***	1.340***
	(0.140)	(0.152)	(0.122)	(0.182)	(0.201)	(0.196)
R&D_COOP	0.095	0.778***	0.236*	0.363**	0.506*	0.273
	(0.156)	(0.136)	(0.128)	(0.157)	(0.289)	(0.185)
LEMPL	0.087***	0.155***	0.076**	0.175***	0.183***	0.128*
	(0.033)	(0.042)	(0.034)	(0.067)	(0.066)	(0.067)
LAGE	0.042	0.150**	-0.013	-0.116	-0.100	-0.127
	(0.061)	(0.077)	(0.060)	(0.085)	(0.090)	(0.101)
FOREIGN	0.152	-0.277*	-0.135	0.059	-0.042	0.049
	(0.122)	(0.151)	(0.123)	(0.204)	(0.207)	(0.199)
IPC	0.028	-0.123*	0.041	0.178**	0.138*	0.160**
	(0.053)	(0.064)	(0.048)	(0.072)	(0.079)	(0.068)
INPC	-0.026	0.124*	0.003	0.263***	0.290***	0.267***
	(0.058)	(0.069)	(0.050)	(0.075)	(0.082)	(0.082)
NCOMP	-0.043	-0.061	0.025	-0.067	-0.066	-0.059
	(0.037)	(0.046)	(0.034)	(0.065)	(0.051)	(0.056)
Const.	-2.850***	-4.581***	-2.947***	-5.268***	-5.371***	-3.604***
	(0.424)	(0.657)	(0.407)	(1.668)	(1.282)	(1.533)
N	1717	1717	1717	1717	1717	1717
N left censored				885	885	885
Pseudo R2	0.087	0.404	0.096	0.119	0.120	0.119
Wald chi2	95.9	285.5	118.9	1953.1	1204.1	1366.8
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000

Note: Controls for technology fields and sectors in all equations; bootstrapping (100 replications) for standard errors in the test equations, ***, ** and * denote statistical significance at the 1%, 5% and 10% test level respectively.