What Inspires Leisure Time Invention?

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Abstract

This paper seeks to understand the intriguing but only sparsely explored phenomenon of "leisure time invention," where the main underlying idea for the new product or process occurs when the inventor is away from the workplace. We add to previous research by focussing on the inventive creativity of the individual researcher, and reassessing the image of researchers inventing during unpaid time – who have often been dispatched as "hobbyists". Based on the responses from a survey of over 3,000 German inventors, we tested hypotheses on the conditions under which leisure time invention is likely to arise. Results suggest that the incidence of leisure time invention is positively related to exposure to a variety of knowledge inputs – but, surprisingly, not to the quality of prior inventive output. Leisure time inventions are more frequently observed in conceptual-based technologies than in science-based technologies, in smaller R&D projects, and in externally financed R&D projects.

1 Introduction

When industrial R&D personnel sharpen their pencils and turn out the lab lights prior to setting off for home, to what extent do they pigeon-hole their creative work, and abandon workplace thinking, to concentrate on the other obligations and pleasures of leisure time? Or do they remain inventive – perhaps even more open to the proverbial "flash of genius"? The fundamental insight leading to a successful invention can be made during (paid) work time, or (unpaid) leisure time. Leisure time inventors are often dispatched as hobbyists, and their inventions disparaged as marginal improvements of low economic value (e.g. Dahlin et al. 2004; Rosenberg 1994). Yet well-known instances of leisure time inventions include the Wright brothers' "flying machine" (e.g. Heinsohn 2007), Fry and Silver's invention of Post-It Notes at 3M (e.g. Reid and De Brentani 2004), the first Apple computer (Åstebro 2003), and Bednorz and Müller's Nobel prize-winning discoveries in superconductivity (Emanuelson 1999).[1] All of these inventions eventually led to multi-billion dollar businesses. This study explores the conditions under which leisure time invention is likely to arise.

[1] The Wright brothers' crucial leisure time insight came from observing how vultures bank their wings when turning in flight. Until then, the problem of how airplanes could turn safely had bedeviled fliers, not infrequently with fatal results. Art Fry, a senior chemist at 3M and a singer in his church choir on Sundays, had been trying to discover a new use for his colleague Spencer Silver's invention of a non-sticky adhesive. Fry reportedly got his flash of genius while his mind was wandering during a sermon: that the adhesive, attached to paper, could provide a reliable means to mark songs in the church hymnal. The prototype for the first Apple computer was built by Wozniak and Jobs in Jobs' parents' garage. For Bednorz and Müller's invention of superconductivity, see Section 2.

The leisure time idea may be inspired while the inventor is pursuing a hobby, exchanging ideas with friends, watching television, or engaging in a recreational activity. Or, like Archimedes, the inventor may be inspired while taking a bath.[2] As Shalley et al. (2004) point out, to better understand the antecedents of creativity, it is beneficial to expand the range of personal and contextual factors investigated. This paper adds to previous research by focusing on the nature of the inventive creativity of the individual researcher, and reassessing the potential contribution that can be made by employees working during unpaid time.

To our knowledge, this is the first empirical survey of the determinants of leisure time invention. Thus far, there has only been some suggestive work on the jointness between leisure time and work time invention (Davis and Davis 2008). Our paper differs from most studies on corporate inventiveness, which focus on organizational design to improve worker creativity and performance (for example, Elsbach and Hargadon 2006; Hargadon 1999; Hargadon and Sutton 1997; Weick 1979, Hackman et al. 1975). Some scholars analyze creativity and the lone inventor (see for example Dahlin et al. 2004; Fleming 2006) or the contribution of independent inventors (Cockburn 2008). While economists have examined unpaid work (subsistence production, housework, work in the informal sector of the economy, and volunteer work, e.g. Beneria 1999), none include inventive activity in their analyses.

In this study, we differentiate between "leisure time invention," and "work time invention," according to the time at which the *main underlying idea* for the invention occurred. The resulting invention may – or may not – be related to the inventor's work time activities. Possibly it was further developed in the inventor's leisure time, but it may also have been developed during work time, or a combination of the two. Our analytical focus is thus at the level of the individual invention.[3]

The key to understanding leisure time invention, we believe, lies in the problem-solving process. We

2 According to legend, Archimedes was given the task of determining the purity of a gold crown presented to the Tyrant of Syracuse. This problem was solved when Archimedes got into his bath and the water overflowed. He suddenly realized that he could use water displacement to work out the volume and density of the crown. Archimedes supposedly shouted "Eureka" - I have found it – and ran home naked in his excitement (see http://scienceworld.wolfram.com/physics/ Buoyancy.html; accessed February 14, 2008).

3 In the PatVal survey, which provides the data on which this paper is based (see Section 4.1), respondents were asked the following question: "Which of the following scenarios describes best the creative process that led to your invention?" Those inventors choosing answer (C): "I got the idea underlying this invention during my leisure time" are, for our purposes, defined as having made a leisure time invention.

ask: what specific conditions might be associated with the leisure time inventor's enhanced ability to solve problems while away from work? Since there are no previous studies of this issue, we sought inspiration in the literature on organizational creativity and the determinants of inventiveness. For example, scholars have argued that conformist workplace pressures such as "groupthink" can decrease creativity (e.g. Janis 1982). Might the leisure time inventor benefit by often engaging in interactions with people outside the workplace? Alternatively, might leisure time invention be linked to exceptional workplace performance? Or could it be that certain types of problems are more easily addressed at home than others – and if so, which?

Based on the responses from a survey of over 3,000 German inventors, we found that the incidence of leisure time invention is positively related to exposure to a variety of external knowledge inputs – but, surprisingly, not to the quality of prior inventive output. Leisure time inventions are more frequently observed in conceptual-based technologies than in science-based technologies, in smaller R&D projects, and in externally financed R&D projects. By widening the scope of inquiry into the process leading to inventive activity, these results have implications both for our theoretical understanding of the inventive process, and for managers seeking to encourage employee creativity.

2 The creative process and leisure time invention

There is a large literature on invention and creativity. The inventive process involves the novel combination of ideas or prior technologies (Gilfillan 1935; Basalla 1988; Hargadon and Sutton 1997; Simonton 1999; Weitzman 1996; Weick 1979), either by combining components of technologies in a new way (Nelson and Winter 1982) or by reconfiguring existing technologies (Hendersen and Clark 1990). The primary focus of this literature is on group invention (Fleming 2006). Discussions of group inventive creativity are often based on social and cognitive psychological sciences, and the effect of combining ideas or perceptions in novel manners. Thus Hargadon (1999) argues:

> Group interactions elicit relevant though often non-obvious knowledge from how individuals regard the current situation or past experiences and trigger creative ways of combining those ideas to solve new problems. In practice, groups often create novel and unexpected combinations of an organization's past knowledge in ways that individuals or more formal organizational structures do not (p. 137).

Today, inventions are typically made by teams in R&D projects. But an individual team member may still contribute the main idea. Therefore, although highly neglected in the existing literature, the single inventor (as a part of an inventor team) is still of utmost importance (Reagans et al. 2005).

There is no literature to guide us in specifying what might be unique about leisure time invention. But arguably, the conditions that inspire people to invent during their leisure time will involve not only a group exchange of ideas (as described, for example, in Hargadon 1999), but also the underlying mental processes of the individual engaged in the creative inventive process. This mental process has best been described by the French genius and polymath Henri Poincaré at the turn of the last century.

> The appearance of sudden illumination is a manifest sign of long unconscious prior work. During a period of apparent rest 'great numbers of combination [of ideas are] blindly formed by the subliminal self. Most are useless and remain unconscious but particularly 'harmonious', 'useful' and 'beautiful' ones may break into consciousness. 'Initial intense prior conscious work on the problem is necessary to 'unhook' relevant ideas from fixed positions so that they are free to join during the unconscious process.' Creativity is the 'conscious but unsuccessful effort to solve a problem sets in motion a conscious process that leads to a random combination of ideas, one of which may emerge as an appropriate creative solution' (Poincaré, as transcribed in R.T. Brown 1989: 5).

Poincaré's observation about how the creative "sudden illumination," if useful and beautiful, might break into consciousness, is underpinned by work on the psychoanalytical approach to creativity (Kris 1952; Kubie 1958; Noy 1969; Rothenberg 1979; Suler 1980; Mumford and Gustafson (forthcoming, 2009). According to Kris (1952), the inventive "flash of genius" seems to be stimulated by the intrusion of stray, "unmodulated" thoughts into consciousness, which can be elaborated and transformed. These thoughts are loose and vague, but interpretable (Kubie 1958). Extending this logic to the leisure time inventive process, we believe that when inventors are at home, they are more likely to be open to the intrusion of unmodulated thoughts, which can then be related to the inventor's existing knowledge, and further developed to create interesting new combinations of knowledge.

Some types of problems may be solved by combining known facts in a new manner; other problems cannot be solved without the addition of new, experimental knowledge. This issue is discussed in the literature on "innovative design" [4] (Hatchuel and Weil 2003; Hatchuel et al. 2003; Tschang and

[4] "Innovative design," proposed by Hatchuel et al. (2003), provides only one approach to facilitate problem solving processes. Another approach, the "Theory of Inventive Problem Solving" (TRIZ), was developed in 1946 by Genrich Altshuller, a Russian mechanical engineer. One of the essential premises of TRIZ is that "inventive problems can be codified, classified and solved methodically" (Kaplan 1996).

Szyzpula 2006). Hatchuel and Weil (2003) suggest that bits of known information can be divided into "knowledge space" and "conceptual space". There are two types of creative processes: (1) *conceptual-based* (design) creativity, where the main underlying knowledge is well known but is applied in conceptually creative manners, expanding the conceptual space, and (2) *science-based* creativity (often involving applied science), where key aspects of the main underlying knowledge do not exist; thus the inventor must experimentally develop new knowledge, expanding the knowledge space.

An example of the conceptual-based inventive process is the *Gossamer Albatross*, a bicycle-powered light aircraft invented by Paul MacCready, which successfully flew across the English Channel in 1979. In 1959, British industrialist Henry Kramer had announced a series of prizes to reward the invention of a human-powered flying machine. In 1971, MacCready, a former gliding champion, founded AeroVironment, a California-based technology company that specialized in helping government meet its environmental and energy objectives. Determined the win the prize, MacCready drew on his leisure time gliding experiences for inspiration. Applying the terminology of Hatchuel and Weil (2003) to this invention, MacCready took the concept of a human-powered flying machine and created various "conceptual partitions," including bicycle pedal power, carbon fiber materials, and a high aspect ratio (size of wings to the overall size of the craft concerned). These concepts were not, as such, part of a logical knowledge space. But by utilizing the known properties of the knowledge space to expand his conceptual space, and creating "conjunctions and disjunctions" between them, MacCready was able to develop an ultra-light but strong aircraft that could be propelled an astonishing 36 kilometers over water by a human being.[5]

An example of the science-based inventive process is the quest for a new oxide superconductor. Bednorz and Müller, top physicists at IBM's Zurich Laboratories, were seeking to develop materials in which an electric current could flow without encountering any resistance. Secretly, in their leisure time

[5] The *Gossamer Albatross,* with its carbon fiber skeleton, weighed just 32 kg. New materials reduced the weight and strengthen the enormous wings (29+ meters in extent) increasing the lift to power ratio; pedal power is the most efficient form of human power, (developing 0.4 hp, enough to propel the aircraft). See the U.S. National Aeronautics and Space Agency's (NASA) Dryden Fact Sheet, available at http://www.nasa.gov/centers/ dryden/news/FactSheets/FS-=054-DFRC.html, and the U.K. Royal Aeronautical Society, "Human Powered Flight Group", available at http://www.raes.org.uk/cmspage.asp?cmsitemid=SG_Hum_Pow_Home,

– but using their employer's lab equipment and materials – they experimented with over 200 different combinations of ceramic oxides (materials discounted by other scientists). Finally, they increased the level of superconductivity from 23.2 degrees Kelvin, where it had been stalled since 1973, to about 30 degrees Kelvin, paving the way for its subsequent widespread industrial use. They worked in secret because their goal – determining whether or not superconductivity could be achieved at higher temperatures – went against the scientific consensus of the time, and they feared their employer would disapprove.[6] Here, the knowledge space was characterized by a highly sophisticated and vast set of knowledge propositions. Müller and Bednorz combined this with the experimental development of new knowledge to make their path-breaking invention.

We believe that leisure time invention is related to the inventor's *enhanced ability to solve problems at home*. Schön (1983) has contended that creativity seems to be enhanced by a combination of worker involvement in, and detachment from, the task at hand. Studies on organizational design have shown how a challenging work environment, extensive decision-making autonomy and exposure to constructive feedback can foster creativity, while high workload and time pressures punctured by frequent interruptions, substantially reduce it (e.g. Amabile et al. 1996, 2002; Fraser 2001; Shalley et al. 2004; Amabile et al. 2001; Perlow 2001). Too much pressure may turn an intellectually challenging and enjoyable job into a stress-inducing and exhausting one. Amabile *et al.* (2002), for example, demonstrate that professional workers who suffer from intense workload and time pressure produce almost half as many creative ideas as they would produce without these pressures. According to Hallowell (2005), when the brain's frontal lobes are overwhelmed by too much information related to decision-making and planning, the ability to solve problems creatively also declines.

To minimize the negative effects of work-related pressures and to increase creativity, the literature proposes giving employees blocks of "free time," to reduce stress and facilitate the cognitive process of reflective thinking (Armbruster 1989). Yet studies have cast doubt on the degree to which creative

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[6] A year after Müller and Bednorz announced their discovery, researchers at the University of Alabama and the University of Houston produced ceramic conductors where superconductivity was achieved at above the temperature of liquid nitrogen, a gigantic breakthrough as it brought such superconductivity within the realm of industrial use. Since industry use of liquid nitrogen as a refrigerant is widespread, this promised to open up many industrial development opportunities. Zero resistance superconductivity may be vital to instrument size, energy conservation, or increased magnetic fields.

ideas actually emerge from such programs (Elsbach and Hargadon 2006; Collins and Amabile 1999; Perlow 1999). Elsbach and Hargadon (2006) suggest instead that employees should be allowed to engage in simple, ‘mindless tasks’ low in cognitive difficulty and performance pressures (like photocopying or unpacking supplies) as part of their normal work schedules, which might help to open up new and more fruitful lines of thinking.

Applying this reasoning to leisure time invention, it seems clear that the ability to engage in ‘mindless tasks’ (Elsbach and Hargadon 2006) is greater at home – such as weeding the garden, or painting the living room – than at work. Moreover, by being away from work, the leisure time inventor can physically absent herself from creativity-killing interruptions from colleagues (Amabile et al. 2002) and information overload (Hallowell 2005). This should also enable the inventor to be more receptive to the “sudden illumination,” as described by Poincaré (quoted in Brown 1989:5, above) – or the intrusion of unmodulated thoughts into consciousness (Kris 1952; Kubie 1958) – that facilitate the creation of salient new combinations of knowledge. Arguably, inventing at home should enable the employee to escape workplace stress, but remain creative.

In the literature on cognitive psychology, Steinbruner (1974) has described the process of “reasoning by analogy,” involving “the application of simple analogies and images to guide problem definition” (Schwenk 1984: 117). In other words, analogies from other or perhaps simpler situations are applied to complex problems to reduce the complexity and uncertainty of a situation. Existing research has shown that reasoning by analogy is an effective mean to generate creative solutions to problems (Huff 1980; Schön 1983).

One further key advantage of working at home is that it frees the individual inventor from the pressures of groupthink. As Janis (1982) has shown, group members often try to strengthen the cohesiveness of the group by discouraging disagreement, including the expression of unique, original, and/or critical ideas outside the prevailing consensus. Creative individuals may also themselves hold back from putting forth ideas to the group to avoid being seen as foolish or unduly provocative. Being away from work enables them to escape these conformist pressures.

Pressures from project leaders or other superiors might also constrain inventiveness. Moon (2005), for instance, argues that while senior researchers at universities have the freedom to select their own research projects, in corporations the R&D managers, rather than the engineers, have the authority to decide on the main research direction. Consequently, inventing during leisure time could free the inventor from hierarchical pressure.

3 Hypotheses

In the following, we propose four hypotheses to test the conditions under which leisure time inventions, in contrast to work time inventions, are likely to arise – given our core argument that the incidence of leisure time invention is related to the inventor's enhanced ability to solve problems while at home. Our hypotheses are inspired by the literature on organizational design, strategic management, the combinatory nature of creativity, the differences between technical fields, and cognitive psychology.

First of all, the workplace includes both high performers – the "stars" of an organization – and average workers (e.g. Kelly and Caplan 1997; Dacey and Lennon 1998). Oldham and Cummings (1996) have demonstrated a relationship between such "stars" and creativity. This relationship is especially strong for individuals confronted by complex tasks, and an encouraging supervisory environment. Kelly and Caplan (1997:133), in their study of the top performers at Bell Labs, found that taking real initiative "means going above and beyond the call of duty." Seeking to solve problems in one's leisure time would seem to be an example of such an extra effort.

The leisure time inventor will arguably also consider inventiveness central to her identity. Farmer et al. (2003), in their work on "creative role identity," show that how we see ourselves – who we think we are – can substantially influence how we act. If an employee knows (and believes in) her own strengths, and chooses to pursue the kinds of problems she is good at solving while away from work, this should encourage the incidence of leisure time inventive activity.

We submit that leisure time invention is more likely to occur for employees with demonstrated inventive skills. A proven track record in inventiveness indicates that a scientist is likely to be able to continue to successfully combine existing ideas in a novel manner (Hargadon 1998). If we extend Schön's (1983) reasoning to the subject of this paper, one might contend that the leisure time inventor is ideally placed to combine both involvement in the task at hand – by demonstrating quality of prior inventive output at work – and detachment from it (by coming home). Therefore, we hypothesize:

***Hypothesis 1**:* *The incidence of leisure time invention will be <u>positively</u> related to the quality of prior inventive output of an inventor*

Furthermore, creativity should be increased by exposure to a wide variety of ideas and components not previously combined (Fleming 2006). The successful inventor should be able to draw on a range of knowledge sources, and build on the latest technical advances. Relevant knowledge inputs may arise in the inventor's own research field, but may well also occur in other fields. Early access to diverse (even contradictory) information and interpretations is central to identifying good ideas (Burt 2004).

However, for the flash of genius both to occur, and to lead to an invention, the inventor must *also* be able to creatively combine different knowledge inputs. The best way to learn about potentially interesting knowledge inputs, we believe, is through interactions with a wide variety of people. In their leisure time, inventors are more likely to meet and communicate with other people outside the workplace, and thereby more likely to become more aware of unexpected potential combinations. Art Fry's crucial insight leading to the invention of Post It Notes, for example, came while he was singing in his church choir (see footnote 1). This logic leads to two hypotheses. First, we believe, interactions with colleagues from the same organization, being more influenced by groupthink and characterized by a narrower range of knowledge inputs, may well discourage leisure time inventive activity. However, interactions with people outside the inventor's own workplace should encourage it:

***Hypothesis 2a**:* *The incidence of leisure time invention will be <u>negatively</u> related to interactions with people from the inventor's own workplace.*

***Hypothesis 2b**:* *The incidence of leisure time invention will be <u>positively</u> related to interactions with people outside the inventor's own workplace.*

Furthermore, we propose that the probability of observing a leisure time invention is related to the type of problem to be solved. In the R&D literature, it is well documented that industries differ in the amount of resources devoted to R&D, and in the determinants of technological opportunity (e.g.

Klevorick et al. 1995). Inventors draw more heavily on science to solve problems in certain fields (especially biotechnology, pharmaceuticals and chemicals) than others (Henderson and Cockburn 1994). Fleming and Sorenson (2004) argue that science is far more valuable to inventors working with highly coupled components than with relatively independent components, since finding new configurations, i.e. solving problems, turned out to be fairly easy in the latter case, whereas the search process was relatively complex for highly coupled components. Research on what differentiates independent inventors from corporate inventors has shown that the former are more successful in generating new combinations of knowledge when they solve problems related to well-codified technologies with more extensive prior art (Fleming 2006), and focus on fixing flawed sub-parts of existing products, not creating entirely new products (Dahlin et al. 2004).

Even though our leisure time inventors were employed, they arguably faced similar difficulties to those of the lone inventor in defining the kinds of problems that can be addressed while away from the workplace. In Section 2, we differentiated between conceptual-based and science-based creativity. Typically, the experimental work required to address problems in science-based technologies can only be carried out in laboratories stocked with advanced, costly, and complex equipment. Conceptual problems, by contrast, "travel home" better. Moreover, since combining different concepts in the conceptual space with relatively well-known propositions in the knowledge space does not necessarily require a high degree of specialization, the potential for making a conceptual breakthrough may be greater. Arguably, then, the crucial leisure time insight leading to the invention will more likely occur in relation to technologies where the specific problem to be addressed can more easily be solved at home. Thus:

Hypothesis 3: *Leisure time invention is more likely to occur in relation to problems in conceptual-based technologies than science-based technologies.*

Finally, the problem-solving process for some inventions can be completed within a relatively short period of time, while other problems require a far greater effort. The resources needed to complete an R&D project include assembling the requisite people, materials, equipment, and working capital. Successful project management involves not only effective resource allocation, but also managing risk and scheduling, along with project teams, and inter-organizational relations (Gray and Larson 2003). A large R&D project would typically require resources beyond those available to the leisure time inventor working at home. Large projects also require the extensive coordination of inputs. Dahlin et al. (2004), for example, found that independent inventors specialized in less detailed inventions than corporate inventors due to resource constraints. For the leisure time idea to be the main inspiration for the invention, the associated R&D project should be small enough to be based on it. Therefore, we propose the following:

***Hypothesis 4**:* *The incidence of leisure time invention will be negatively related to the size of the project.*

4 Data source and sample

4.1 Description of the dataset

The survey data were collected for a project sponsored by the European Commission, PatVal ("The Value of European Patents: Empirical Models and Policy Implications Based on a Survey of European Inventors"). 10,500 EP patents listing inventors living in Germany at the time of the application of the patent were chosen by stratified random sampling, based on a list of all granted EP patents with priority dates between 1993 and 1997 (15,595 EP patents). A stratified random sample was used to oversample potentially important patents.[7] Information about the inventions was obtained using a questionnaire divided into six sections. Section A covered personal information about the inventors; Section B, their educational backgrounds; Section C, employment and mobility; Section D, the invention process; Section E, the inventors' rewards; and Section F, the economic and strategic value of the patents. As the addressee of the survey, the first inventor listed on the patent document was chosen. 3,346 responses were received, resulting in a response rate of 32%.

[7] The sample of 10,500 patents hence includes all patents an opposition was filed against by a third party (1,048) and patents which were not opposed but received at least one citation (5,333), and a random sample of 4,119 patents drawn from the remaining 9,212 patents.

The inventors in this study include both scientists employed in a corporate R&D department (employee-inventors, comprising 92.4% of our sample), and self-employed inventors (7.6%)[8]. All variables were constructed at the level of the invention.

4.2. Definition of the variables and descriptive statistics

4.2.1 Dependent variables

Leisure time invention **-** This dummy variable measures whether the idea for the invention came up during the inventor's leisure time or work time.

4.2.2 Explanatory variables

Quality of prior inventive output – We employed patent citation data[9] as a proxy for this. To compare citation counts between inventors, we used the number of citations received within 5 years after publication of the search report for the relevant European patent application. The quality of the invention was then measured as the number of x-type citations[10] divided by the total number of citations received by those patent applications (listing the names of the respondents) filed within one year prior to the patent application under consideration.

Interactions with others – Respondents were asked about the importance of meetings or discussions with others (apart from the co-inventors listed on the patent) during the research process leading to the

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8 The German Employees' Inventions Act applies to all patentable inventions (patented or not) as well as to any other technical improvement proposals (§§2, 3 ArbNErfG) made by inventors in organizations which are governed under German law. Employee-inventors, i.e. inventors who are employed with such organizations, fall under the ArbNErfG and self-employed inventors do not fall under this law. According to the law, employee-inventors have to report their inventions to the employer and the employer can claim the right to the invention. In case the employer does not claim the right to an invention, the invention becomes free and can be exploited by the employee-inventor himself. For inventions made during leisure time, the law is also applicable if the invention is somehow related to the work of the employee-inventor or in case the employee-inventor used resources of his employer to make the invention. In our sample, for 99.2% of the employee-inventions the employer claimed the right to the invention, i.e. only 0.8% of the employee-inventions are owned by the inventors (see http://www.arbeitnehmererfindergesetz.de, accessed February 14, 2008).

9 The number of citations a patent receives is a proxy for the value of a patent. Citations are calculated on the basis of the references published in the search reports of the patent examiners (Harhoff et al. 1999). The data were obtained from the citation database established within the Patent Citation Project 2007 (Harhoff 2007).

10 EPO patent data assign references to certain categories. All documents that appear in the search report are identified by a particular letter representing the referenced category. X-type references are the most important ones as to patentability of an invention. In case an application receives an x-type reference, this indicates that the claimed invention may not meet the requirements of novelty or of inventive step (Harhoff et al. 2008). See also EPO Guidelines for Examination in the European Patent Office, 2007, 188ff.

invention. Four categories were distinguished: (1) people who work in the same organization and can be reached in less than one hour, (2) people in the same organization who take more than an hour to reach, (3) people from other organizations who can be reached in less than one hour, and (4) people from other organizations who take more than an hour to reach. Four dummy variables were created, each taking the value 1 where the respondent regarded the type of interaction as important during the process leading to the main insight underlying the invention, and zero if not.

Type of technical problem – As a proxy for this, we used the IPC class to which the European Patent Office assigned the invention. The IPC classification contains more than 60.000 technical classes, which Schmoch (OECD, 1994) combined to form six main technical areas: (1) electricity/electronics, (2) instruments, (3) chemicals/pharmaceuticals, (4) process engineering, (5) mechanical engineering, and (6) consumer goods/civil engineering. To test hypothesis 3, we classified the main technical areas according to degree of science dependency. While technical problems addressed in chemicals/pharmaceuticals are clearly science-dependent, problems in instruments, process engineering, and consumer goods/civil engineering are more conceptual (science dependency is low). Problems in electricity/electronics and mechanical engineering do not unambiguously fall into either category; therefore, we characterized them as of medium science dependency. Three dummy variables were created representing the types of problems addressed (the dummies are thus mutually exclusive).

Project size – Here we used the total labor input needed as a proxy.[11] A set of five dummy variables was generated. The intervals are "less than 1 man-month[12]", "1-3 man-months", "4-6 man-months", "7-12 man-months", "more than 12 man-months". The first category, "less than 1 man-month," was used as a reference group. In the survey, the size of the project was requested *ex-post*. Thus ideas which were not further developed in an R&D project, and projects which were stopped very early, are characterized by a lower labor input. To avoid biased results due to the *ex-post* measurement of the

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11 At this point, it is important to mention that project size is not a proxy for the value of the project. Whereas the value of a patent refers to the output, this variable is an input measure.

12 A man month refers to the amount of work done by an average worker in one month (excluding breaks or holidays), i.e. it refers to the total amount of uninterrupted labor required to perform a task (see http://dictionary.reference.com/browse/personyear, accessed on July 7, 2008).

project size, we tested hypothesis 4 only for those ideas which were further developed in the R&D project.[13]

4.2.3 Control variables

Our theoretical framework comprises those variables we believe are most closely related to the problem-solving process that can lead to a leisure time invention. But other factors might also be important, such as the personal characteristics of the inventor, or certain features of the work environment, and should be controlled for in our analysis.

Age – The variable shows the age of the inventor at the time of the survey. Leisure time inspirations are arguably more likely to come from older scientists and engineers, with their exposure to more diverse knowledge types (Milliken et al. 2003). As people grow older, they should gain a better overview of different technical fields, and the opportunities for recombination. Moreover, since many are promoted to senior management positions (Roberts and Biddle 1994), the only time they can invent may be in their leisure time.

Level of education - Respondents were asked to name their highest educational degree: (1) secondary school, high school diploma, or vocational training (reference group), (2) vocational academy (Berufsakademie) or university studies, or (3) doctoral or postdoctoral studies. The highest degree is used as a measure for inventor ability (Griliches 1970),[14] which should be positively related to the incidence of leisure time invention.

Intrinsic motivation – Inspired by Gambardella et al. (2007), we controlled for the inventors' motivation to invent. Respondents were asked to rate the importance of the rewards for making the invention, "prestige/reputation," and "satisfaction to show that something is technically possible," on a

13 To test hypothesis 4 conditional on a further development in R&D, we use interaction terms "project size * idea further developed". The variable "idea further developed" is a dummy, which takes the value one in case the idea was further developed and zero, in case the idea has never been further pursued in R&D. If the "idea further developed" dummy is zero, the interaction term "project size * idea further developed" also becomes zero. Consequently, those cases are not considered for the test of hypothesis 4.

14 Griliches (1970) proposed that "ability is the product of 'learning', even if it is not all a product of 'schooling'" (Griliches 1970: 93). Moreover, he suggested to "confess ignorance" with respect to the potential determinants of ability and to define ability as gross output of the schooling system (Griliches 1970).

five-point Likert Scale (1 = absolutely not important; 5 = very important). Where they rated *both* as very important (= 5), the intrinsic motivation dummy was set to one. Greater intrinsic motivation should be a predictor of why an employee would voluntarily use her free time to invent.

Employee mobility – Following earlier studies on mobility (e.g. Hoisl 2007a), a variable was created indicating whether the inventor changed jobs at least once in his career. Employee mobility brings insights and inspirations from the inventor's former workplace. Since this gives the inventor a more diverse background, it should be positively related to the incidence of leisure time invention.

Type of Organization – This dummy variable was set to one if the inventor was employed by a firm, and zero if the inventor worked for a public or a private research institute, or a university. We would expect to observe more leisure time inventions for people employed with research institutes and universities, since these inventors have more flexible work schedules, implying a possible overlap between leisure time and work time (Stern 1999). In addition, the latter category of researchers are more free to choose their own research agendas (Moon 2005).

Size of the inventor team – This variable refers to the number of inventors listed on the patent document. Team size is included in the regression to control for both the allocation of resources in different R&D projects, and for firm size (Hoisl 2007b, showed that the size of the inventor team increases with the size of the firm).

Employee inventor – This measure controls for whether the inventor is an employee-inventor according to the German Employees' Inventions Act (GEIA), or a self-employed inventor. Arguably, there would be a lower incidence of leisure time inventions for self-employed individuals, since they would tend to have less leisure time than people employed by a company (Hamilton 2000).

Financing of R&D – This dummy was set to one if the research leading to the invention was funded by the patent applicant's internal sources, and zero if funded by external sources (e.g., unaffiliated organizations, government, or financial intermediaries). As proposed in hypothesis 4, leisure time invention should occur in smaller projects. Since smaller projects are also more likely to be internally financed, the same logic should apply here, unless the source of financing *per se* is important.[15]

Number of recent inventions – Perhaps leisure time inventions – at least to a certain extent - occur by accident. Therefore, the probability of observing a leisure time invention should increase with the number of inventions made by an inventor. To avoid biased results for the explanatory variables, we needed to control for this. For each respondent, we counted the number of other patent applications in our sample that also listed his or her name as an inventor during the one year period prior to the date of the patent application. This was used as a proxy for the number of the respondent's recent inventions.

4.3 Descriptive statistics

Table 1 provides summary statistics for the variables used in the multivariate analysis for leisure time inventions (6%) and work time inventions (94%), respectively.

(Insert Table 1 about here)

In principle, Table 1 confirms that leisure time inventions are different from work time inventions. Leisure time inventors interacted relatively more frequently with people from other organizations. Leisure time inventions were less likely to address science based problems than conceptual based problems. The median project size for leisure time inventions was lower than for work time inventions, and the probability that a leisure time idea was further developed in an R&D project was considerably smaller (64% vs. 83%).

Employees who made a leisure time invention were two years older, on average, than employees who made a work time invention, and less well educated (13% fewer had a doctoral or post-doctoral degree). 30% of the leisure time inventions were made by mobile inventors (2% lower than for work time inventions). They applied for slightly more patents than work time inventors, but the differences are not significant.

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[15] In addition, Hall (2005) argues that one reason for underinvestment in innovation is that "small and new innovative firms experience high costs of capital," and must therefore rely on internal financing rather than venture capital or other external sources.

The correlation matrix is reported in Table 2. Correlations are relatively low, indicating that multicollinearity should not be a concern.

(Insert Table 2 about here)

5 Model specification and estimation results

Since the dependent variable is a binary-coded variable, a probit model for binary outcomes was used to explore the effect of the explanatory variables on whether or not the invention was made during the inventor's leisure time. The probability of observing a leisure time invention was calculated as a function of a number of independent variables:

$$\Pr(leisure\_time = 1 \mid x) = \Phi(\beta_0 + \beta_1 quality\_output + \sum_i \beta_{2,i} interactions_i + \sum_k \beta_{3,k} technology_k + \sum_j \beta_{4,j}\, project\_size_j + \sum_l \beta_{5,l} control_l)$$

Table 3 shows the results of our empirical analysis. Three specifications were used to explain the incidence of leisure time invention. Specification (1) contains only the control variables. Specification (2) additionally includes the explanatory variables used to test the hypotheses. Specification (3) also includes interaction terms to appropriately test hypothesis 4. In the following, only the outcomes of Specification (3) will be reported, unless otherwise stated.

(Insert Table 3 about here)

Surprisingly, we found that the quality of the inventions made within the last year does not significantly affect the probability of a leisure time invention (hypothesis 1). Thus our assumption that "star inventors" are more likely to have the critical creative insight during leisure time than work time is not supported by the data.

Leisure time inventions are 3% less likely to occur for employees who interact frequently with fellow workers in the same organization who can be reached in less than one hour. (They are also slightly less likely for employees who interact with co-workers more than one hour away, though the result is not significant). By contrast, interactions with people in other organizations are 3% (distance ≤ 1 driving hour) or 2% (distance > 1 driving hour) *more* likely lead to leisure time inventions. Overall, hypotheses 2a and 2b are confirmed by the data.

Furthermore, our results confirm hypothesis 3. The likelihood of observing a leisure time invention for problems in conceptual-based technologies (instruments, consumer goods or process engineering) is 2% greater than for problems in science-based technologies (chemicals and pharmaceuticals), our reference group. The effect is significant at the 10% level. The category "medium science-based problems" is not significant compared to the reference group.

According to Model (2), inventions further developed within an R&D project are 3% less likely to be leisure time inventions. We needed to take this finding into account when testing the relationship between the incidence of leisure time invention and project size. Interaction terms were factored into the regression to measure the effect of project size on the probability of observing a leisure time invention where the idea was further developed in the R&D project. Results reveal negative and mostly significant effects of project size (conditional on further development in the R&D project) on the dependent variable. For instance, if the idea for the invention was further developed, and project size equals a total labor input of 1 to 3 man months, the probability of a leisure time invention decreases by 6% (-0.039+(-0.073)+0.049=-0.064) compared to the reference group (where project size equals a labor input of less than 1 man month). Although hypothesis 4 is largely confirmed by the data, the relationship between the size of the project and the incidence of a leisure time invention is still ambiguous, and should be analyzed more closely in further research.

The control variables reveal that an inverted u-shaped relationship exists between the age of the inventors and the probability of a leisure time invention. Additionally, in Model (1), we find that there is a smaller likelihood of observing a leisure time invention for inventors who earned a doctoral or a post-doctoral degree. A possible explanation could be that, in Germany, the percentage of employees who have earned a Ph.D. is highest in chemicals and pharmaceuticals (which are science-based), compared to other technical fields. Thus the negative and significant effect of education may well be driven by the technology rather than the level of education. This assumption is confirmed by the outcomes of Models (2) and (3), which – after including the dummies capturing the type of problem -

exhibit an insignificant effect of the variable “doctoral or post-doctoral studies”. In particular, in Model (3), the size of the effect is halved in value, and is only significant at the 10% level.

Finally, self-employed inventors are significantly more likely to invent in their leisure time, confirming our expectation that for this group, leisure time and work time may be difficult to separate. Leisure time inventions occur more often in externally financed R&D projects. The probability of observing a leisure time invention increases slightly with the number of inventions made within the last year. In Model (1), two of the control variables, the type of organization employing the inventor and the size of the inventor team, have a significant positive effect on the incidence of leisure time invention. However, in Models (2) and (3), which also include the explanatory variables, the effect of both controls is insignificant, indicating that our explanatory variables also capture these effects. Neither intrinsic motivation nor employee mobility can explain the incidence of leisure time invention.

6 Discussion and Conclusion

6.1 Main findings

From Archimedes’ famous bath to Bednorz and Müller’s path-breaking discoveries in superconductivity, the invention literature is replete with stories of how critical inventive insights have occurred during the inventor’s leisure time. Working with the PatVal dataset, we sought to explain what might trigger the leisure time inventive inspiration. Our analysis has uncovered several key characteristics of the leisure time inventive process.

As regards the nature of the problem-solving process, we found that interactions with people outside the workplace (hypothesis 2a and 2b), increased the probability of leisure time invention, but that the quality of the inventors’ recent inventions (hypothesis 1) was not significant. What seems to spark the leisure time insight is not inventive capability *per se*, but exposure to a wide variety of external knowledge inputs.

Our second main category of results concerns the nature of the problem to be solved. Leisure time inventions are more frequently observed in conceptual-based technologies than in science-based technologies (hypothesis 3), and in smaller R&D projects (hypothesis 4). Returning to our discussion of “innovative design” in Section 2, this indicates that inventions like the *Gossamer Albatross* are more likely to occur during leisure time than inventions requiring highly sophisticated laboratory equipment, as exemplified by Bednorz and Müller’s inventions in superconductivity.

Taken together, these results suggest that what might be unique about leisure time invention is that the inventor, working at home, is able to pursue what he defines as important, shielded from the work time pressures of groupthink and hierarchical decision-making – but that he is also constrained as regards the kinds of inventions that can be made, since certain types of problems “travel home” better than others.

6.2 Limitations

Two limitations of this study should be mentioned. First, the inventors we surveyed are listed on at least one granted EP patent. Therefore, we cannot assume that our results apply to the full population of (German) inventors. In particular, not all inventions are patented or patentable (Cohen et al. 2000). Second, we use survey data to analyze the process of invention. But we observe only one inventor from the inventor team. As mentioned at the beginning of this paper, inventions are generally made in teams. We recognize that as a result, the data provide an incomplete coverage of innovative activity.

6.3 Implications and suggestions for future research

Since this paper, as far as we are aware, is the first to examine the amorphous phenomenon of leisure time invention empirically, our conclusions must necessarily be tentative. But several interesting questions raised by our analysis might be highlighted. First, how can managers best realize the potential benefits from leisure time inventive activity? In Section 3, we noted that corporate programs that give employees the opportunity for unstructured free time do not necessarily achieve their goals of enhancing creativity. Our study suggests that when inventors are both away from work and in frequent contact with people from other organizations, they are more open to Poincaré’s “sudden illumination” that can lead to salient new combinations of knowledge. To encourage this kind of creativity, managers might consider implementing programs to facilitate such interactions. In addition, since leisure time inventions are less likely to occur in science-based than conceptual-based technologies, managers of science-based firms might try to find new ways to encourage employees to find alternative solutions to work time problems while at home.

Related to this, there might be a need to develop new tools enabling managers to be better able to "span the boundary" between – and know when and when not to embrace – inventive activity at home (or work) that also continues at work (or home). One possible approach would be to legitimatize certain leisure time inventive activities within the firm. Given that many engineers, scientists and other highly skilled workers initially prefer lower wage jobs characterized by higher learning potential (and consequently higher future wages), a solution might be to "package" what some employees would be doing in their leisure time into the overall employee learning experience.

Stern (1999: 28), in an analysis of research biologists working in biotechnology firms, found that researchers allowed to engage in "open science" were willing to "pay a compensating wage differential" for the possibility to do so. This might have implications for leisure time invention. Our findings suggest that workplace generation of what would otherwise be leisure time know-how need not necessarily have negative consequences for a firm's bottom line. Nevertheless, employers cannot encourage every form of leisure time activity. Some of it may, in fact, be unproductive, or even counter-productive, given the firm's own mission and objectives. Future scholarship could seek to illuminate these issues.

An interesting question raised by these findings, and one that we intend to pursue in future research, concerns the relationship between the leisure time insight and the value of the resulting invention. For example, the existing literature demonstrates that inventions made by independent or lone inventors are characterized by a higher variability in value. Even if the average value of sole inventions might be lower than that of collaborative inventions, the probability that a sole invention ends up being a breakthrough invention is much higher (Fleming 2006; Dahlin et al. 2004; Åstebro 2003; Nelson 1959). Can the same logic be applied to the value of leisure time inventions? If so, what factors might explain when leisure time inventions are more valuable than work time inventions?

Another fruitful topic for further research would be to explore the individual characteristics of leisure time inventors. Do they exhibit common personality traits? Scholars have shown that personal characteristics, such as ease with complex matters and with ambiguity, self-confidence, and intuitive capability contribute to individual creative performance across a variety of domains (e.g. Barron and Harrington 1981, Martindale 1989). One could assume that these qualities are also characteristic of the inventors who solve problems during their leisure time. It would be interesting to see whether such individuals are also more likely to be struck by the creative flash of genius in their leisure time.

Related to this, one could ask: Are people who are inclined to be hobbyists more creative than other people? Hobbyists have extensive contacts with outside organizations which, in our study, have been seen to be positively correlated with leisure time inventions. There is empirical evidence that the leisure time pursuit of hobbies is linked to individual creativity (see the review article by Barron and Harrington 1981). Other studies (e.g. Weick and Eakin 2005) touch more explicitly on the relationship between hobby activities and creativity. Many hobbies cannot be linked to creativity. Yet some managers use employee hobbies to influence their personnel policies.[16]

Finally, recent years have seen a blurring of the boundaries between paid and unpaid work. To what extent are "virtual workers" who are linked to their workplace via the Internet engaging in paid work, or leisure time work? Many professionals check their e-mails at night or over the weekend, or sometimes even on vacation. Is physical distance the defining characteristic of the leisure time inventor, or mental distance? While our data do not allow us to answer such questions, our results do underline the advantages for creativity of keeping work time and leisure time activities – at least to a certain degree – *separate*.

[16] Thus the director of Sherwood Business Management Corporation advises his readers in ***Metal Finishing*** magazine: "Discover the most creative individuals by asking them about their hobbies. High on the list are painting, antique car refurbishing, interior decorating, handicrafts and model making. Down at the bottom are beer drinking TV watching and spectator sports. Give the high-end people special projects to work on. Encourage the low-end people despite the indicated minimum potential" (Sherwood 2006: 55)

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Table 1: Descriptive statistics (N_{tot} = 2,542)

	leisure time invention (N=149)				work time invention (N=2393)			
variable	mean	S.D.	min	max	mean	S.D.	min	max
quality of prior inventive output	1.50	2.99	0	17	1.73	3.31	0	28
interactions with fellow employees								
same organization (≤ 1 hour) *	0.46		0	1	0.68		0	1
same organization (> 1 hour)	0.17		0	1	0.22		0	1
other organization (≤ 1 hour) *	0.17		0	1	0.13		0	1
other organization (> 1 hour)	0.30		0	1	0.25		0	1
type of problem								
science based problem *	0.12		0	1	0.26		0	1
medium science based problem	0.40		0	1	0.38		0	1
conceptual based problem *	0.48		0	1	0.35		0	1
project size (man months)♦ *	2[3]		1	5	3[3]		1	5
idea further developed in R&D project *	0.64		0	1	0.83		0	1
age at the time of the survey **	51.42	9.12	31	72	49.20	9.71	24	83
education (terminal degree) *								
high school diploma or less	0.17		0	1	0.11		0	1
university studies	0.59		0	1	0.52		0	1
doctoral/postdoctoral studies	0.24		0	1	0.37		0	1
high intrinsic motivation	0.47		0	1	0.45		0	1
employee mobility	0.30		0	1	0.32		0	1
type of the organization: firm *	0.91		0	1	0.96		0	1
size of the inventor team **	2.41	1.75	1	10	2.98	1.97	1	16
status employee-inventor *	0.85		0	1	0.96		0	1
financial resources: internal funds *	0.89		0	1	0.95		0	1
no. of patent applications (1 year prior)	3.36	4.74	1	30	3.28	3.81	1	58

♦ median

* in a Chi2-Test, the difference between leisure time and work time invention turned out to be significant

** in a t-test, the difference between leisure time and work time invention turned out to be significant

[1] 1 = “less than € 30T”, 2 = “€ 30T - € 100T”, 3 = “€ 100T - € 300T”, 4 = “€ 300T - € 1 mio.”, 5 = “€ 1 mio. - € 3 mio.”, 6 = “€ 3 mio. - € 10 mio.”, 7 = “above € 10 mio.”

[2] 1 = “top 10%”, 2 = “top 25%, but not top 10%”, 3 = “top 50%, but not top 25%”, 4 = “bottom 50%”

[3] 1 = “less than 1 man-month”, 2 = “1-3 man-months”, 3 = “4-6 man-months”, 4 = “7-12 man-months”, 5 = “more than 12 man-months”

Table 2: Correlation matrix (N_{tot} = 2,542)

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) leisure time	1																			
(2) quality of prior inventive output	-0.02	1																		
(3) same organization (<= 1 h)	-0.11	0.07	1																	
(4) same organization (> 1 h)	-0.03	0.06	0.22	1																
(5) other organization (<= 1 h)	0.03	0.04	0.15	0.20	1															
(6) other organization (> 1 h)	0.03	0.01	0.14	0.17	0.30	1														
(7) science based problem	-0.08	0.18	0.10	0.02	-0.01	-0.02	1													
(8) medium science based problem	0.01	-0.06	-0.02	0.02	0.00	0.02	-0.46	1												
(9) conceptual based problem	0.06	-0.10	-0.07	-0.04	0.01	-0.01	-0.44	-0.59	1											
(10) project size	-0.10	0.07	0.17	0.10	0.14	0.14	0.22	-0.14	-0.06	1										
(11) idea developed in R&D project	-0.12	0.10	0.14	0.07	0.05	0.07	0.13	-0.06	-0.06	0.24	1									
(12) age of the inventor	0.05	-0.05	-0.16	-0.03	-0.04	-0.01	-0.03	-0.02	0.05	-0.06	-0.11	1								
(13) education	-0.07	0.20	0.13	0.08	0.04	0.04	0.41	-0.22	-0.15	0.21	0.17	-0.09	1							
(14) intrinsic motivation	0.01	0.00	0.00	0.04	0.02	0.02	0.03	-0.03	0.01	0.03	0.01	0.10	-0.03	1						
(15) employee mobility	-0.01	0.09	-0.02	0.05	0.02	0.02	0.06	-0.03	-0.03	0.05	0.04	0.08	0.10	0.04	1					
(16) type of organization: firm	-0.06	0.05	0.05	0.04	-0.08	-0.08	0.01	0.05	-0.06	-0.12	-0.03	0.01	-0.09	0.02	-0.06	1				
(17) size of inventor team	-0.07	0.15	0.11	0.05	0.06	0.00	0.32	-0.17	-0.11	0.21	0.13	-0.05	0.27	0.00	0.06	-0.04	1			
(18) status employee-inventor	-0.11	0.04	0.15	0.04	-0.02	-0.04	0.07	0.01	-0.07	-0.02	0.06	-0.11	0.03	-0.04	-0.04	0.24	0.11	1		
(19) financing: internal funds	-0.07	0.01	0.04	0.03	-0.02	-0.02	0.07	-0.04	-0.02	-0.02	0.03	-0.02	0.00	0.04	-0.02	0.28	0.02	0.08	1	
(20) no. of patent applications (1 yr prior)	0.00	0.41	0.08	0.03	0.03	-0.04	0.25	-0.11	-0.12	0.03	0.08	-0.01	0.21	0.04	0.08	0.06	0.18	0.04	0.05	1

Pearson correlation coefficients (for two continuous variables) / Point biserial coefficient (for one continuous variable and one dummy variable) / Phi coefficient (for two dummy variables)

Table 3: Probit model (marginal effects) (N_{tot} = 2,542)

	Model (1)	Model (2)	Model (3)
Dependent variable	leisure time invention		
quality of prior inventive output		-0.0001	-0.00004
		[0.001]	[0.001]
type of interaction			
own organization (distance <= 1 hour)		-0.031***	-0.030***
		[0.010]	[0.010]
own organization (distance > 1 hour)		-0.002	-0.001
		[0.010]	[0.010]
other organization (distance <= 1 hour)		0.027*	0.028*
		[0.016]	[0.016]
other organization (distance > 1 hour)		0.024**	0.024**
		[0.011]	[0.011]
type of problem (reference group: science based problem)			
medium science based problem		0.010	0.010
		[0.014]	[0.013]
conceptual based problem		0.022*	0.022*
		[0.014]	[0.014]
project size (reference group: labor input 'less than 1 man month')			
1 to 3 man months (mm)		-0.022**	-0.039***
		[0.009]	[0.012]
4 to 6 men-months		-0.028***	-0.043**
		[0.008]	[0.013]
7 to 12 man months		-0.022**	-0.056**
		[0.010]	[0.012]
more than 13 man months		-0.039***	-0.042
		[0.008]	[0.020]
idea further developed in R&D project		-0.032***	-0.073***
		[0.012]	[0.026]
1 to 3 mm * further developed			0.049*
			[0.033]
4 to 6 mm * further developed			0.050
			[0.044]
7 to 12 mm * further developed			0.185**
			[0.130]
> 12 mm * further developed			0.017
			[0.047]
age of the inventor (in 10 years)	0.118**	0.085**	0.089**
	[0.047]	[0.042]	[0.042]
age of the inventor (in 10 years) (squared)	-0.011**	-0.008*	-0.008**
	[0.005]	[0.004]	[0.004]
level of education (reference group: high school diploma or less)			
university studies	-0.011	-0.008	-0.007
	[0.013]	[0.012]	[0.012]
doctoral/post doctoral studies	-0.035***	-0.019	-0.021
	[0.013]	[0.013]	[0.012]
high intrinsic motivation	0.001	0.002	0.001
	[0.009]	[0.008]	[0.008]
employee mobility	-0.008	-0.006	-0.005
	[0.009]	[0.008]	[0.008]
type of the organization: firm	-0.045*	-0.034	-0.033
	[0.032]	[0.028]	[0.028]
size of the inventor team	-0.006**	-0.002	-0.002
	[0.003]	[0.002]	[0.002]
status employee-inventor	-0.084***	-0.059***	-0.065***
	[0.031]	[0.027]	[0.028]
financial resources: internal funds	-0.052**	-0.044**	-0.044**
	[0.027]	[0.024]	[0.025]
number of inventions (1 year prior)	0.002*	0.002*	0.002*
	[0.001]	[0.001]	[0.001]
constant	-3.100***	-2.399**	-2.340**
	[1.128]	[1.174]	[1.179]
Pseudo R2	0.053	0.106	0.113
Log likelihood	-537.0	-507.1	-503.1
Chi2-test	60.5; p = 0.00	120.2; p = 0.00	128.2; p = 0.00

N = 2,542 / Standard errors in brackets / * significant at 10%; ** significant at 5%; *** significant at 1%