Leisure Time Invention – Waste of Effort, or Wellspring of Breakthrough Ideas?

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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 occurred when the inventor was 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 3,000 German inventors, we test hypotheses on the conditions under which leisure time invention is likely to arise, and how valuable it is. We find that the incidence of leisure time invention is positively related to high workplace inventive productivity, and exposure to a variety of knowledge inputs. Leisure time inventions are more frequently observed in conceptual-based technologies than science-based technologies, and in smaller R&D projects. The average value of leisure time inventions exceeds the value of work time inventions.

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? The fundamental insight leading to a successful invention can be made during paid 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' early 20th century "flying machine" (e.g. Heinsohn, 2007), Fry and Silver's invention of Post-It Notes at 3M in the 1970s (e.g. Reid and De Brentani, 2004), and Bednorz and Müller's Nobel prize-winning discoveries in the field of superconductivity in 1986 (Emanuelson, 1999).[1] All these inventions eventually led to multi-billion dollar businesses.

[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. Bednorz and Müller, top scientists at IBM's Zurich Laboratories, had to work secretly in their leisure time to determine whether or not superconductivity could be achieved at higher temperatures, since their goal went against the scientific consensus of the time, and they feared their employer would disapprove (see Section 2).

This study explores the degree to which leisure time invention can be dismissed as a waste of effort – or a source of breakthrough ideas. Under what conditions is it likely to arise? Is it more prevalent for certain types of projects than others? How valuable is it? We differentiate between "leisure time invention," and "work time invention," according to the time at which the *main underlying idea* for the invention occurred.[2] Possibly the resulting invention was further developed in the inventor's leisure time, but it may equally have been developed during work time, or a combination of the two. Our analytical focus is thus at the level of the individual invention, not the inventor.

The leisure time inventors in this study have a range of backgrounds. They include scientists employed in a corporate R&D department (employee-inventors; 92.4%), and self-employed (or free) inventors (7.6%)[3]. The idea may have been inspired while pursuing a hobby, exchanging ideas with friends, watching television, or engaging in a recreational activity. Or, like Archimedes, they may have been inspired while taking a bath.[4]

To our knowledge, this is the first empirical survey of the determinants of the incidence and value of leisure time invention. There has been some suggestive work on the jointness between leisure time and work time invention (Davis and Davis, 2007a; 2007b). In an empirical study of the incentive effects of

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[2] 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.

[3] 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 or in German subsidiaries of international organizations. Employee-inventors, i.e. inventors who are employed with such organizations fall under the ArbNErfG and free inventors, who are self-employed, 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).

[4] According to legend, Archimedes was given the task of determining the purity of a crown presented to the Tyrant of Syracuse. This problem was solved when Archimedes got into his bath and saw it overflow, he suddenly realised 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).

the German Employees' Inventions Act, Harhoff and Hoisl (2007) note that the economic value of leisure time inventions is higher than the value of workplace inventions, but do not explore why.

Our paper differs from most studies on corporate inventiveness, which focus on organizational design to improve worker creativity (for example, Elsbach and Hargadon, 2006, Hargadon, 1999; Hargadon and Sutton, 1997; Weick, 1979, Hackman *et al.*, 1975). Some work analyzes creativity and the lone inventor (see for example Dahlin *et al*, 2004; Fleming, 2006). Economists have examined the value of unpaid work (subsistence production, housework, work in the informal sector of the economy, and volunteer work, e.g. Beneria, 1999), but none include inventive activity in their analyses.

Our arguments are organized as follows. Section 2 explores the nature of leisure time invention. Section 3 proposes five hypotheses to test the conditions under which inventions inspired during leisure time are likely to arise, and how valuable the patents granted to these inventions are. Section 4 presents the data source and sample. Section 5.1 sets forth the model specification and estimation. The results of the analysis are discussed in Section 5.2, followed by the conclusion.

2 The characteristics of 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 novel manner (Nelson and Winter, 1982) or by reconfiguration of existing technologies (Hendersen and Clark, 1990). One implication is that creativity should be increased by exposure to a wide variety of ideas and components not previously combined (Burt, 2004). The primary focus of this work 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 new 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).

Typically, inventions are made by teams in huge 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.

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).

To probe the essence of leisure time invention, we need to understand what might be unique about the dynamics of the creative process *outside* the workplace. Central to achieving this understanding, we believe, is the literature on the conditions under which the proverbial "flash of genius" might occur.

Poincaré's observation is underpinned by the psychoanalytic approaches to creativity that explore the tension between conscious and unconscious drives (Kris, 1952, Kubie, 1958; for more recent work, see Noy, 1969, Rothenberg, 1979, Suler, 1980, and Mumford and Gustafson, 1996). Kris (1952) considers the role of adaptive regression and elaboration. Adaptive regression, as a primary process, refers to the intrusion of unmodulated thoughts in consciousness, which may stimulate creativity. Unmodulated thoughts can occur during active problem solving, but often occur in sleep, intoxication, fantasies, daydreams or psychoses. Elaboration as a secondary process refers to the reworking and transformation of primary process material through reality-oriented ego-controlled thinking. Kubie (1958) emphasized the preconscious, which falls between conscious reality and the encrypted consciousness, as the true source of creativity, because thoughts are loose and vague but interpretable. A particularly valuable insight concerns the double role of the unconscious, which can also be a barrier to creative thinking, especially if the unconscious leads to fixated, repetitive thinking.

But how can these creative combinations of leisure time subconscious and conscious thoughts or concepts be applied to the inventive process? Hatchuel *et al.* (2003, 2004) suggest that bits of known information can be divided into two categories: "knowledge space" (a set of relevant propositions for the creative agent), and "concepts" (propositions which have no logical space in the knowledge space). Creativity involves the process by which propositions from the knowledge space are transformed into new concepts, and by which conceptual propositions are incorporated into a new extended knowledge space. These scholars distinguish between two major types of inventive process: those where there are many concepts and conceivable conceptual partitions (conceptual-based, Type I creativity) and those involving "sophisticated knowledge with a limited conceptual development," (science-based, Type II creativity). In both cases, it is necessary to winnow through many different concepts/combinations to achieve a specific set of events, identified through knowledge space propositions.

Two examples help us to extend this logic to leisure time invention. On June 12, 1979, the *Gossamer Albatross*, a human-powered light aircraft invented by Paul Macready, made the first successful 36 kilometer flight across the English Channel. Macready's insight was to take the concept of a human-powered flying machine and create various conceptual partitions: bicycles, pedal power, carbon fiber materials, polystyrene, transparent mylar wrapping, a high aspect ratio (size of wings to the overall size of the craft concerned). These concepts meant nothing in themselves as they were not, as such, part of a logical knowledge space (they did not answer to the question "true or false"). They could, however, be related to the existing knowledge space: the weight of the vehicle should be light (the *Gossamer Albatross* weighed 32 kg); new materials would contribute to reducing weight and to strengthening 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). Using Hatchuel *et al's* (2003) terminology, Macready was utilizing the known properties in the knowledge space (K) to expand his conceptual space (C), and vice versa, creating "conjunctions and disjunctions between K and C". This interaction led to the expansion of both what is known in the knowledge space, and the number of concepts in C (for example, an ultra-light but strong carbon fiber skeleton).

Compare this with Mueller and Bednorz's quest for a new oxide superconductor. Here, the knowledge (K) space was vast. The goal was to develop materials in which electrical current could flow without encountering any resistance. Secretly, in their leisure time – but using the lab equipment and materials of their employer, IBM Zurich – the two scientists experimented with over 200 different combinations of ceramic oxides (materials discounted by other scientists). Eventually, they successfully increased the level of superconductivity from 23.2K, where it had been stalled since 1973, to about 30 K, paving the way for its subsequent widespread industrial use.[5]

With the *Gossamer Albatross,* there were many different concepts and a relatively well known set of knowledge space propositions (conceptual-based, Type I creativity). With superconductivity, by contrast, there were relatively fewer concepts – arguably just one: that a particular ceramic oxide could be found with zero resistance superconductivity above 30K – but a highly sophisticated and vast set of knowledge propositions in the knowledge space (science-based, Type II, creativity).

3 Hypotheses

This section develops hypotheses to explain the incidence and value of leisure time invention. Our hypotheses are inspired by the literature on strategic management, the combinatory nature of creativity, the differences between technical fields, and cognitive psychology.

3.1 The problem-solving process

First, we believe, the probability to observe a leisure time invention is related to the inventor's *enhanced ability to solve problems* while away from work. Studies on organizational design show 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, Hackman *et al.,*

[5] A year after Mueller 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 opened up many industrial development opportunities. Zero resistance superconductivity may be vital to instrument size, energy conservation, or increased magnetic fields.

1975, Shalley *et al.*, 2004, Mueller *et al.*, 2001, Perlow, 2001). Putting employees under too much pressure may turn an intellectually challenging and enjoyable job into a stress-inducing and exhausting one. Amabile *et al.* (2002), for example, show 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, a person's ability to solve problems creatively also declines. In such cases, lower performance pressures should enhance creativity (e.g. Glynn, 1994, Carver and Scheier, 1994).

To overcome workload pressure, the literature proposes 'free time,' which reduces stress and facilitates the cognitive process of reflective thinking, an important determinant of creativity (Armbruster, 1989). Elsbach and Hargadon (2006) suggest allowing employees 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. This should help to free their minds from unproductive fixations on difficult tasks, potentially opening up new and more fruitful lines of thinking (Smith, 1995; Elsbach and Hargadon, 2006). Creativity seems to be enhanced by a combination of worker involvement in, and detachment from, the task at hand (Schön, 1983).

We submit that the leisure time inventor is ideally placed to combine both. If we extend Elsbach and Hargadon's (2006) logic to the leisure time inventor, the potential to engage in mindless tasks should arguably be greater away from work (such as weeding the garden or taking out the trash), than at work. More generally, by being physically absent from work, the inventor can better escape creativity-killing workload pressures (Amabile *et al.*, 2002) and information overload (Hallowell, 2005). This should *ceteris paribus* make the leisure time inventor more receptive to "stray" ideas that might contribute to potentially interesting new combinations of knowledge (Kris, 1952, Kubie, 1958).

A proven track record in inventiveness indicates that a scientist is able to combine existing ideas in a novel manner. A scientist who exhibits a currently highly productive level of inventive activity will *ceteris paribus* also be more likely to continue to be a successful inventor. But such a scientist is also vulnerable to the negative effects of acute workload pressures. We would expect, therefore, that a highly productive researcher's problem-solving capabilities will be enhanced by the opportunity to enjoy "free time" at home. During work time, the exceptionally productive researcher is intensely focused on the task at hand, and therefore less likely to be open to "stray" ideas that might contribute to interesting new combinations of knowledge. During leisure time, the inventor should be more receptive to such ideas. This leads to our first hypothesis:

Hypothesis 1: *The incidence of leisure time invention will be positively related to the current inventive output of an inventor.*

Moreover, the successful inventor must 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. Thus we would predict that unless the inventor is *both* receptive to the intrusion of unmodulated thoughts (including ability to suppress the more fixated subconscious thoughts that inhibit creativity, e.g. Kris, 1952, Kubie, 1958), *and* has been exposed to a wide variety of knowledge inputs that can potentially be combinable in a novel manner (Burt, 2004), the idea for the invention is unlikely to occur. Arguably, exposure to potentially promising combinations of new knowledge is best achieved if the inventor has previously engaged in problem-solving activities with many *different* people, including both people working in the same organization, and people working in different organizations. It can be assumed that the inventor is best able to combine these external sources of knowledge and to suppress more fixated ideas in case she is freed from workload pressures, i.e. during leisure time. This leads to our second hypothesis:

Hypothesis 2: *The incidence of leisure time invention will be positively related to the extent to which the inventor engages in interactions with both co-workers and people outside the workplace.*

3.2 The nature of the technology concerned

In addition, the probability to observe a leisure time invention should be 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). In Section 2, we differentiated between conceptual-based (Type I) and science-based (Type II) creativity (Hatchuel *et al.*, 2003). There are far higher uncertainties associated with science-based inventions than conceptual-based inventions. Moreover, combining many different concepts in the conceptual space with relatively well-known propositions in the knowledge space normally does not require a high degree of specialization, and should therefore allow for a greater number of potential inventions. Arguably, the leisure time insight arising from the preconscious (Kubie, 1958) will more likely occur in relation to projects where the problem to be solved is relatively clearly, and narrowly, defined. If the problem is too complex, it is probably solved by teamwork. Thus:

Hypothesis 3: *Leisure time invention occurs more frequently in conceptual-based technologies than science-based technologies.*

Related to this, some types of inventions can be created with relatively few resources, in a relatively short period of time, while others require a far greater resource commitment. Arguably, large projects would necessitate not only resources beyond those available to the leisure time inventor, but also the extensive coordination of inputs from a variety of sources. Therefore, we propose the following:

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

3.3 The value of leisure time invention

While the generation of new combinations of existing knowledge can lead to inventions, this is no guarantee of success. In the following, we present three arguments as to why ideas created during leisure time may be more valuable than ideas that arise during work time.

First, as described in Section 2, invention involves a process of recombination. But what makes some combinations more valuable than others? March and Simon (1958) assume that firms' R&D activity is mainly characterized by activities closely related to their core technological domains (local search). Others contend that "combinative capability", the ability to move beyond local search, increases the probability of achieving sustainable competitive advantage (e.g. Kogut and Zander, 1992, Rosenkopf and Nerkar, 2001). Fleming and Sorenson (2004) show empirically that applying knowledge from other domains (such as relying on research results from science) enhances technological innovation, since it alters conventional search processes and makes them less path dependent. Arguably, the leisure time inventor is uniquely advantaged in this respect, since she can engage in a range of different activities during her leisure time, with a variety of different people, counteracting the tendencies toward path dependency. To the degree that the leisure time inventor is thereby more likely to be struck by new, unexpected perspectives on stubborn problems that have so far eluded solution, the resulting inventions will *ceteris paribus* be more valuable. However, there may be a limitation: The literature on social networks shows that people tend to choose friends those similar to themselves (Blau, 1974; Granovetter, 1983). Thus, seeking advice from friends during leisure time may lead to the exchange of path dependent or even redundant information.

Second, while an intrinsically motivating work environment increases creative output, a high-pressure workplace decreases it (see Section 3.1). But organizational remedies designed to overcome such negative workplace pressures, like giving employees blocks of free time or the chance to interact with each other off-site, can in practice be difficult to implement effectively (e.g. Armbruster, 1989, Elsbach and Hargadon, 2006). For example, studies have cast doubt on the degree to which creative ideas actually emerge from programs granting unstructured employee free time (Staw, 1995). Managers may not respect such programs when faced with high workload pressures (Collins and Amabile, 1999, Perlow 1999). Off-site "brainstorming" sessions often serve other purposes, such as generating status competitions among professionals within the organization, or impressing outsiders (e.g. Sutton and Hargadon, 1996). To the degree that these organizational remedies do not work, the intended output (in the form of commercially valuable inventions) will not be realized. The leisure time inventor, by definition, is not subject to these pressures. Consequently, it is reasonable to expect that leisure time inspirations will lead to more valuable inventions.

Our third argument comes from the literature on cognitive psychology. In 1974, Steinbruner 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 showed that reasoning by analogy is an effective mean to generate creative solutions to problems (Huff, 1980; Schön, 1983). With respect to leisure time invention we assume that concepts from other domains may inspire inventors to overcome fixated subconscious ideas and to find solutions for R&D problems that may also be of higher value compared to ideas that came up during work time. In sum, this reasoning leads us to our final hypothesis:

Hypothesis 5: *The value of patents granted to leisure time inventions will be greater than that of patents granted to work time inventions.*

4 Data source and sample

4.1 Description of the dataset

The 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.[6] Information about the patented 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%.

The questionnaire data were merged with bibliographic and procedural information on the respective patents from the online EPOLINE database. The database contains information on all published EP patent applications as well as all published PCT applications since 1978. The dataset corresponds to the EPOLINE data as of March 1st, 2003. All variables were constructed at the level of the invention.

[6] 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.

4.2. Definition of the variables and descriptive statistics

4.2.1 Dependent variables

Leisure time invention - This dummy variable reflects the creative process underlying an invention, in particular, if the idea for the invention came up during the inventor's leisure time or work time.

Patent value (1): asset value – Following Harhoff et al. (2003) we define the value of a patent as the asset value, which approximates the prize received by the winner of a patent race. Inventors were asked to estimate the asset value of the patent for a particular invention using the following question:

> *This is a hypothetical question. "Suppose that on the day of the grant of this patent, the applicant had all the information about the value of the patent that is available today. In case the strongest competitor of the applicant was interested in buying the patent, what minimum price (in Euro) should the applicant have demanded?"*

The intervals were "less than € 30,000", "€ 30,000 - € 100,000", "€ 100,000 - € 300,000", "€ 300,000 - € 1 mio.", "€ 1 mio. - € 3 mio.", "€ 3 mio. - € 10 mio.", "above € 10 mio.".

Patent value (2): strategic and economic value – A second value measure will be used for a robustness check. Inventors were asked to assess the economic and strategic value of the patent compared to other patents in the same industry or technological field. Possible answers were: the patent belongs to (1) top 10%, (2) top 25%, but not top 10%, (3) top 50%, but not top 25%, and (4) bottom 50%.

Patent value (3): size of the patent family – A patent family is defined as "all the documents having at least one priority in common"[7]. We use the number of designated states as a proxy for the size of the patent family. To validate a European patent, the applicant must pay a fee, translate the patent into the language of each validation country, and pay renewal fees in each country. Thus this variable can be seen as a good measure for the value of a patent (Guellec and van Pottelsberghe, 2000).

4.2.2 Explanatory variables

Current inventive output – The number of patent applications listing the names of the respondents within a period of one year before the invention under consideration is used as a proxy for this.

[7] See http://gb.espacenet.com/espacenet/gb/en/help/161.htm, accessed on July 10, 2008.

Interactions with fellow employees – Respondents were asked about the importance of meetings or discussions with others (apart from co-inventors) during the research process leading to the patented 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 can only be reached in more than one hour, (3) people from other organizations who can be reached in less than one hour, and (4) people from other organizations who can be reached in more than one hour. Four dummy variables were created, each taking the value 1 in case the respondent regarded the respective type of interaction as important for inventive activity, and zero otherwise.

Main technical field - Based on the International Patent Classification (IPC), with more than 60.000 technical classes, the patents were classified into six main technical areas: electricity/electronics, instruments, chemicals/pharmaceuticals, process engineering, mechanical engineering, and consumer goods/civil engineering (a classification proposed by Schmoch, OECD, 1994). To test hypothesis 3, we classified the 6 technical areas according to the degree of science dependency. Whereas chemicals/pharmaceuticals are clearly science dependent and instruments, process engineering, and consumer goods/civil engineering are more conceptually based technologies, i.e. science dependency is low; electricity/electronics and mechanical engineering do not unambiguously fall in one or the other category. Therefore, we assume a medium science dependency for the latter two fields.

Resources – The number of man-months invested in the research leading to the patent is used to measure the resources allocated to the research project, i.e. the size of the R&D project.[8] A set of five dummy variables was generated. The intervals are "less than 1 man-month[9]", "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" is used as a reference group. In the survey, the resources allocated to the project was requested *ex-post*, i.e. ideas which have not been further developed in an R&D project, and projects which were stopped very early, are characterized by making fewer resources available. To avoid biased results, we

8 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.

9 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).

test hypothesis 4 conditional on a further development of the idea in an R&D project (i.e. we use interaction terms "research time * idea further developed").

4.2.3 Control variables

Our theoretical framework comprises those variables which the literature disclosed as most relevant in explaining the creative process behind an invention, and the value of the resulting invention. But other factors, like the characteristics of the inventors, might also be important. In the value regression, we control for the determinants of patent value which are proposed in the earlier literature (e.g., Harhoff et al. 2003; Gambardella et al., 2006).

Age – The variable shows the age of the inventor at the time of the survey. Leisure time inventions are more likely to be inspired by older scientists and engineers, since they will have had more exposure to more diverse knowledge types. Age is also a proxy for experience and should therefore be positively related to patent value.

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 proxy for inventor ability,[10] which should be positively related to both incidence and value.

Intrinsic motivation – The inventors 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 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.

Employee mobility – A variable was created indicating whether the inventor changed his employer at least once in his career. Employee mobility brings insights and inspirations from the inventor's former workplace, and gives the inventor a more diverse background.

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[10] 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).

Type of Organization – This dummy variable is set to one if the inventor is employed by a firm, and zero if the inventor works for a public or a private research institute, or a university. We expect to observe more leisure time inventions for inventors employed with research institutes and universities.

Employee inventor – This measure controls for whether the inventor is an employee-inventor according to the German Employees' Inventions Act (GEIA), or a free inventor. The latter are assumed to be organized more flexibly, and work time and leisure time might be difficult to separate.

Financing of R&D – The dummy takes the value one if the research leading to the patented invention was funded by the applicant's internal sources, zero if funded by external sources (e.g., unaffiliated organizations, government, or financial intermediaries). As proposed in hypothesis 4, leisure time invention should occur more often in smaller projects, which we believe are more likely to be internally financed.

PCT application - A dummy variable is factored into the value model if a PCT application has been filed for this patent. A PCT application is assumed to be positively related to the value of a patent.

Number of claims - The number of claims per patent is used as a proxy for the scope of an invention for which patent protection is requested. Within the value regression, this variable is used to control for heterogeneity that would otherwise lead to biased coefficients of the explanatory variables.

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%), separately. Leisure time inventions occur in all kinds of organizations irrespective of size or industry, including widely diversified corporations (e.g., SIEMENS or PHILIPS), large chemical firms (e.g., BAYER), the automobile industry (e.g., FORD or BMW), as well as small and medium sized enterprises (e.g., MELITTA).

(Insert Table 1 about here)

In principle, Table 1 confirms that leisure time inventions are different from work time inventions. The median of the asset value of leisure time inventions is higher than that of work time inventions. However, the difference is not significant. The strategic and economic value of leisure time inventions is slightly but significantly higher than that of work time inventions. The size of the patent family of leisure time inventions is significantly larger than for work time inventions.

Moreover, inventors for whom we observe a leisure time invention are two years older than inventors of work time inventions, on average, and less well educated (13% fewer have a doctoral or post-doctoral degree). 30% of the leisure time inventions were made by mobile inventors (2% higher than for work time inventions). Inventors responsible for leisure time inventions interacted more often with colleagues from other organizations, while inventors who made work time inventions interacted more extensively with colleagues employed with the same organization.

The median of the resources assigned to leisure time inventions is lower than that for work time inventions. This is not surprising, since the probability that an idea was further developed in an R&D project is significantly smaller for leisure time inventions (83% vs. 64%). Leisure time inventions also arise less often in chemicals/pharmaceuticals, and more often in process engineering, mechanical engineering and consumer goods & civil engineering. 85% of the leisure time inventions were made by employee-inventors: the corresponding figure for work time inventions is 96%. Finally, leisure time inventions are less often financed using internal funds. All differences are significant.

Figure 1 shows a histogram of the distribution of patent asset value. The shares are provided for both sub-samples separately. While patents granted to leisure time inventions dominate the categories of high value patents (>3 mio €), the categories of low value patents (<300 T €) are dominated by work time inventions. This finding is in line with the earlier literature. Figure 1 also indicates that, whereas the value of work time inventions follows a right-skewed distribution, the value distribution of patents on leisure time inventions is more ambiguous.

(Insert Figure 1 about here)

5 Model specification and estimation results

5.1 Treatment-effects model

We model the value of the patented inventions as a function of the characteristics of the invention process, in particular, whether the idea for the invention came up during leisure time or work time.

Using an OLS regression model or an ordered probit model to estimate patent value would lead to inconsistent estimates, if we assume that the "decision" whether an invention is made during leisure time or work time is not at random. For instance, characteristics of the project or of the inventors that can not be observed may influence the process of idea generation and the value of the invention. In that case, the error terms of the two models (estimation of the probability to observe a leisure time invention and the value regression) are correlated and, consequently, the outcomes are biased.

To account for this bias, we use a treatment-effects model.

$$y_j = \beta x_j + \delta z_j + \varepsilon_j$$

where y_j is the value of the patent, x_j and w_j denote explanatory variables, and z_j is the endogenous dummy variable (leisure time invention or not). The binary decision to receive the treatment z_j is modeled as the outcome of an unobserved latent variable, z_j^*. It is assumed that z_j^* is a linear function of the exogenous covariates w_j and a random component u_j. Specifically,

$$z_j^* = \gamma w_j + u_j$$

and the observed decision is

$$z_j = \begin{cases} 1, & if\ z_j^* > 0 \\ 0, & otherwise \end{cases}$$

Consequently, we model the decision of a leisure time invention or a work time invention as a function of a number of explanatory variables which may also affect the value of the patents and of at least one variable that only affects the decision "leisure time invention or not" but not the value of the patents (Imbens and Angrist, 1994; Vella and Verbeek, 1999). Two variables turned out to work as such an identification variable, i.e. the status of the inventor (employee-inventor or free inventor) and the financing of the R&D project (internal or external funds).

5.2 Results

Table 2 summarizes the results of the probit model that accounts for the incidence of leisure time invention. The marginal effects are displayed in column 2.

(Insert Table 2 about here)

A higher current inventive output was assumed to increase the probability of leisure time invention. The data confirm this relationship, i.e. hypothesis 1 is confirmed by the data. In particular, five more patent applications in the year before the invention under consideration significantly increases the probability of a leisure time invention by 1%.

Results also show that inventors who interact frequently with co-workers and other people outside the workplace are 3% (distance ≤ 1 driving hour) or 2% (distance > 1 driving hour) more likely to engage in leisure time invention. But interactions with fellow employees who work in the same organization and who can be reached within less than one hour by car decrease the probability of a leisure time invention by 3%. Overall, hypothesis 2 is confirmed by the data.

Our results in part confirm hypothesis 3, that leisure time inventions occur more often in conceptual-based technologies like instruments, consumer goods or process engineering, than in science based technologies, like chemicals and pharmaceuticals. The likelihood of observing a leisure time invention in process engineering is 3% greater than in chemicals and pharmaceuticals (reference group). The effect is significant at the 10% level. Process engineering is the only technical area that exhibits a significant effect compared to the reference group. However, a Wald test confirmed joint significance of the technical field dummies (chi2(10) = 18.06, p = 0.054). Finally, the size of the coefficients is consistent with our ranking of the technological areas regarding science dependency, which was proposed in the data section.

Inventions further developed within an R&D project are 6% less likely to be leisure time inventions. To account for the future exploitation of the ideas, interaction terms were factored into the regression, measuring the effect of project size on the probability of leisure time invention in case the idea was further developed in an R&D project. Results reveal negative and mostly significant effects of the interaction terms on the dependent variable. In particular, if the idea for the invention was further developed within an R&D project and research times amounted to 1 to 3 man months, the probability of a leisure time invention decreases by 6% compared to the reference group (less than 1 man month). The probability of a leisure time invention is lowest for projects that involved resources of more than 13 man months (decrease by 9% compared to the reference group). Although hypothesis 4 is largely confirmed by the data, the relationship between project size and the incidence of a leisure time invention is still ambiguous, and has to 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. Neither level of education, nor the type of organization employing the inventor, significantly affect the incidence of leisure time inventions. The two variables used as identification variables in the treatment-effects model, i.e. the status of the inventor and financial resources, do have a significant influence on the dependent variable. The status employee-inventor has a negative effect on the probability that an idea for an invention comes up during leisure time, and leisure time inventions are more often financed by external funds.

Table A1 (see appendix) provides the outcomes of two value (asset value) regressions. Column 1 summarizes the results of an ordered probit model, which best fits the ordinal structure of the dependent variable. Column 2 gives the results of an OLS regression model. These two models do not take into account the selection of inventions into the groups ‘leisure time invention’ or ‘work time invention’. Therefore, we will not interpret the results of the two models. However, it is important to show that the results of the OLS regression model (column 2) and those of the ordered probit model (column 1) are consistent with respect to the sign and the significance of the coefficients. The treatment effects model uses an OLS regression model to estimate the asset value of the patents, even though an ordered probit regression would better fit the ordinal structure of the value variable.

Table 3 shows the results of the treatment-effects model. Column 1 provides the results of the probit analyzing the probability of the incidence of leisure time inventions. Column 2 summarizes the results of the asset value regression which corrects for the self-selection effect by including the estimates of the endogenous dummy variable (leisure time or not) into the value regression. The model tests the null hypothesis that the coefficients for corresponding variables in the selection model and the ordinary OLS model are identical. Results show that the null hypothesis can be rejected (lambda = -0.561; p = 0.040), i.e. the two models estimating the asset value of the patents lead to different results. Thus the application of the two-step model is appropriate. Additionally, it should be mentioned that the size of the effect of leisure time invention on asset patent value changes considerably when using the treatment-effects model, i.e. the effect increases by a factor of 3. In case the invention came up during the inventor's leisure time the asset value of the patents significantly increases by 1.62, which can be interpreted as a shift upwards by one value category. Consequently, the data also support hypothesis 5.

Most of the other explanatory variables also have a significant effect on the value of the patent. Especially, the resources (research time), the technical areas and the indicators of the asset patent value proposed by the earlier literature (Harhoff et al. 2003), i.e. PCT applications and the number of claims show the expected signs and are highly significant.

(Insert Table 3 about here)

As a robustness check, two other measures for patent value were employed. First, we used the strategic and economic value of the patents. Results are consistent. In particular, leisure time inventions significantly increase the strategic and economic value of patents by 1.31. Again, the application of a treatment-effects model turns out to be appropriate (lambda = -0.468; p = 0.016).

It is possible that inventors might overestimate the value of patents granted to inventions they made during their leisure time, leading to biased results in our multivariate analysis. To test whether our results might be biased, we include another value measure which is independent from the inventors' assessment, the size of the patent family (Guellec and van Pottelsberghe, 2000). Results reveal a positive effect of leisure time inventions on patent value. In particular, family size increases by 4.5 in case of a leisure time invention. The effect is significant at the 1% level. The model also reveals a selection effect caused by leisure time inventions (lambda = -1.897; p = 0.006). Overall, the effect of leisure time invention on the asset value, the strategic and economic value of the patents, and the size of the patent family is positive and significant.

Finally, we present the results of another two robustness checks. To avoid biases caused by inventions made by researchers with a flexible work schedule (where the distinction between work time and leisure time is difficult or impossible), the treatment-effects model in Table A2 (see appendix) excludes self-employed inventors (free inventors) and inventors employed with public research institutes or universities. Overall, results are consistent with the results for the full sample (Table 3). The effect of leisure time inventions on the asset value of patents is still positive and significant. However, the null hypothesis that the coefficients for corresponding variables in the selection model and the ordinary OLS model are identical can no longer be rejected (lambda = -0.445; p = 0.167). This result is very interesting, since it implies that the employment status of the inventor is a driver of the selection effect.

Finally, one could object that leisure time inventions occur by accident. Thus highly productive inventors are both more likely to make leisure time inventions, and to hold the most valuable patents. In other words, the positive relationship between leisure time inventions and patent value may be driven by the productivity of an inventor. To show that the above outlined argumentation does not apply to our data, a final robustness check was conducted. The sample was restricted to inventions made by inventors who hold 10 patents or less (compared to the full sample: each inventor is on average responsible for 14.9 patents, ranging between 1 and 394 patents per inventor). Results again reveal a positive and significant relationship between leisure time inventions and patent value, which is highly significant. Again the model confirms a selection effect, and, therefore, the appropriateness of the selection-effects model (lambda = -0.878; p = 0.005).

6 Conclusion

From Archimedes' famous bath to Paul Macready's ingenious combination of bicycle power and super-light super-strong plastic materials to create the *Gossamer Albatross*, the invention literature is replete with stories of how critical inventive insights have occurred not while the inventor was at work, but while he was otherwise engaged, what we term leisure time invention. Working with the PatVal dataset, we have sought to explain what inspires leisure time invention, and the value of the resulting patents. To this end, we adopted a relatively broad theoretical model in an effort to identify interesting phenomena to investigate. Since this paper, as far as we are aware, is the first to examine this amorphous phenomenon empirically, our conclusions must necessarily be tentative.

We found that leisure time invention has its own very specific characteristics. Some are environmental (lack of access to internal corporate resources, the nature of collegial relationships, and the inventor's age). Others have more to do with the technical nature of leisure time invention. Our overall results confirm that leisure time invention is positively related to the both to the inventor's ability to combine existing ideas in a novel manner, and the ability to suppress the more fixated subconscious thoughts. It also occurs more often in conceptual-based technologies than in science-based technologies.

Moreover, we found that both the asset value and the strategic and economic value of such inventions exceed the value of work time inventions, and that leisure time inventions are positively related to the size of the patent family. Although the outcomes unambiguously reveal a positive link between leisure time inventions and patent value, this should be subject to further research. It might, for instance, be interesting to explore possible alternative explanations for our findings on patent value. Perhaps people who work in their firm's R&D labs would be directed towards solving specific problems. Or, following March (1991), inventors may well concentrate on "exploitation" during work time, and "exploration" during leisure time, since exploitation is characterized by lower uncertainty and is likely to bear fruit in a shorter time. Conducting exploration processes in leisure time enables the inventor to fulfill immediate work goals (during work time) and "at the same time" express creativity (during leisure time). Both processes differ with respect to the expected value of the outcome, its variablility and the planning interval. As a result, work time inventions might be less valuable because they would be to a certain extent "predictable" – or at least more predictable than leisure time inventions.

Several implications of our analysis might be highlighted. First, since the patents granted to leisure time invention are more valuable than those for work time invention, how can managers best realize the potential benefits from leisure time inventions? In Section 3.3, we noted that corporate programs that give employees the opportunity for unstructured free time do not necessarily achieve their goals of enhancing creativity. In testing hypothesis 1, we found that a wide variety of interactions with both co-workers and people outside the workplace increases the incidence of leisure time inventions. What makes the leisure time inventor "different" is that, simply by being away from the workplace, she is able to distance herself from the task at hand. Our results can thus be said to support Elsbach and Hardagon's (2006) idea of allowing employees to engage in "mindless" tasks at work, to the extent that such tasks can help workers create mental distance from their normal work pressures. A further implication is that managers who drive their employees to work ever longer hours may reap short-term productivity benefits, but perhaps lose the longer-term benefits from employee inventiveness.

There is a need to develop new management 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 low 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 biotech firms, found that researchers allowed to engage in "open science" were willing to "pay a compensating wage differential" for the possibility to do so. These findings might have implications for leisure time invention. Workplace generation of what would otherwise be leisure time know-how need not necessarily have negative consequences for a firm's bottom line, if workers are prepared to settle for less in return for increased learning experience.

A further key set of issues concerns what leisure time invention actually is in the Knowledge Era, especially in light of the expansion of the Internet. 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 suggest that it is vital to creativity to keep work time and leisure time activities separate.

Another topic for further studies would be to explore the individual characteristics of leisure time inventors. Do they exhibit common personality traits? 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 individual pursuit of hobbies, by definition a use of leisure time, 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 are using employee hobbies to influence their personnel policies.[11]

Finally, the existing literature demonstrates that inventions made by independent or lone inventors are characterized by a higher variability of the value. Even if the average value of sole inventions might be lower than that of collaborative inventions, the probability that an invention will turn out to be a breakthrough invention is much higher (Fleming, 2006; Dahlin *et al.*, 2004; Åstebro, 2003; Nelson, 1959). Relating these findings could provide a further fruitful avenue for research.

[11] 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, handi-crafts 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)

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
asset value of the patent♦	4		1	7	3		1	7
strategic/economic value of the patent♦*	3		1	4	2		1	4
size of the patent family **	8.41	4.55	1	18	7.81	4.01	1	18
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
current inventive output	3.36	4.74	1	30	3.28	3.81	1	58
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
main technical field *								
electricity / electronics	0.11		0	1	0.15		0	1
instruments	0.11		0	1	0.10		0	1
chemicals / pharmaceuticals	0.12		0	1	0.26		0	1
process engineering	0.26		0	1	0.19		0	1
mechanical engineering	0.30		0	1	0.24		0	1
consumer goods / civil engineering	0.10		0	1	0.06		0	1
research time (man months)♦ *	2		1	7	3		1	7
idea further developed in R&D project *	0.64		0	1	0.83		0	1
status employee-inventor *	0.85		0	1	0.96		0	1
type of the organization: firm *	0.91		0	1	0.96		0	1
financial resources: internal funds *	0.89		0	1	0.95		0	1
size of the inventor team **	2.41	1.75	1	10	2.98	1.97	1	16
sole inventor *	0.42	0.49	0	1	0.23	0.42	0	1
PCT application filed	0.29		0	1	0.26		0	1
number of claims	10.81	7.46	1	49	10.58	7.34	1	131

♦ 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

Figure 1: Asset value of the patents (N = 2,542)

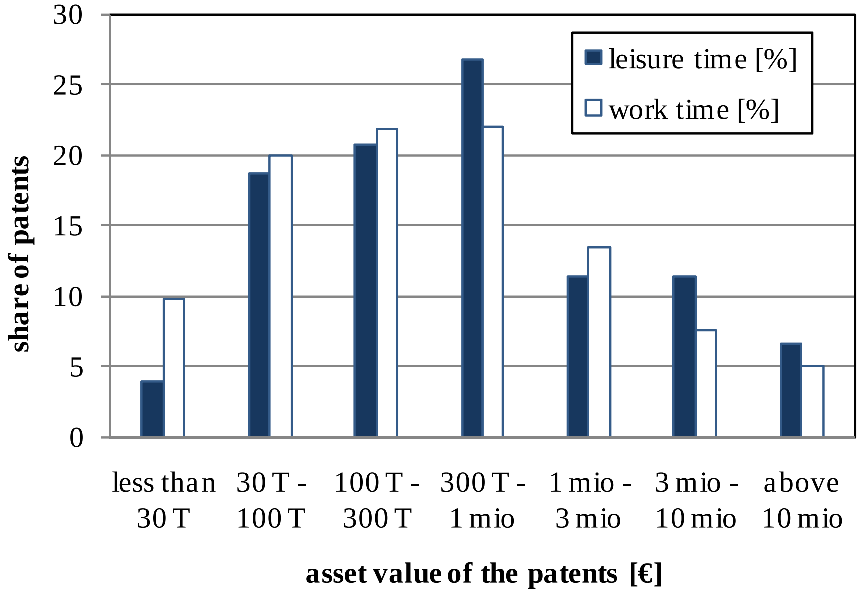

Table 2: Probit analysis of leisure time inventions (N = 2,542).

	probit		Dprobit/dx	
	leisure time invention		leisure time invention	
age of the inventor	0.099**	[0.046]	0.009**	[0.004]
age of the inventor (squared)	-0.001**	[0.000]	-0.0001**	[0.000]
level of education (reference group: high school diploma or less)				
university studies	-0.084	[0.129]	-0.008	[0.012]
doctoral/post doctoral studies	-0.249	[0.153]	-0.021	[0.012]
high intrinsic motivation	0.015	[0.087]	0.001	[0.008]
employee mobility	-0.056	[0.095]	-0.005	[0.008]
current inventive output	0.019*	[0.011]	0.002*	[0.001]
type of interaction				
own organization (distance <= 1 hour)	-0.304***	[0.094]	-0.030***	[0.010]
own organization (distance > 1 hour)	-0.009	[0.116]	-0.001	[0.010]
other organization (distance <= 1 hour)	0.256**	[0.129]	0.027**	[0.016]
other organization (distance > 1 hour)	0.236**	[0.103]	0.024**	[0.011]
main technical field (reference group: chemicals & pharmaceuticals)				
electricity & electronics	0.003	[0.174]	0.0003	[0.016]
instruments	0.218	[0.175]	0.023	[0.021]
process engineering	0.257*	[0.150]	0.027*	[0.018]
mechanical engineering	0.190	[0.149]	0.019	[0.016]
consumer goods & civil engineering	0.283	[0.195]	0.031	[0.026]
research time (reference group: less than 1 man month)				
1 to 3 man months (mm)	-0.526***	[0.189]	-0.039***	[0.012]
4 to 6 man months	-0.631**	[0.262]	-0.042**	[0.013]
7 to 12 man months	-1.185**	[0.469]	-0.056**	[0.012]
more than 13 man months	-0.632	[0.400]	-0.042	[0.019]
idea further developed in R&D project	-0.572***	[0.160]	-0.071***	[0.026]
1 to 3 mm * further developed	0.431*	[0.237]	0.048*	[0.033]
4 to 6 mm * further developed	0.408	[0.305]	0.046	[0.043]
7 to 12 mm * further developed	1.096**	[0.497]	0.190**	[0.133]
> 13 mm * further developed	0.157	[0.436]	0.015	[0.047]
status employee-inventor	-0.511***	[0.156]	-0.067***	[0.028]
type of the organization: firm	-0.281	[0.205]	-0.031	[0.028]
financial resources: internal funds	-0.384**	[0.163]	-0.046**	[0.025]
Constant	-2.385**	[1.174]		
Observations	2542		2542	
Pseudo R2	0.1139			
Chi2-test	chi2(28) = 129.16; p = 0.000			

Standard errors in brackets / * significant at 10%; ** significant at 5%; *** significant at 1%

Table 3: Treatment-effects model (N = 2,542)

	treatment-effects model			
	probit		OLS	
	leisure time invention		asset value	
leisure time invention (dummy)			1.623***	[0.551]
age of the inventor	0.099**	[0.046]	0.007**	[0.003]
age of the inventor (squared)	-0.001**	[0.000]		
level of education (reference group: high school diploma or less)				
university studies	-0.084	[0.129]	0.108	[0.104]
doctoral/post doctoral studies	-0.249	[0.153]	-0.006	[0.115]
high intrinsic motivation	0.015	[0.087]		
employee mobility	-0.056	[0.095]		
current inventive output	0.019*	[0.011]		
type of interaction				
own organization (distance <= 1 hour)	-0.304***	[0.094]		
own organization (distance > 1 hour)	-0.009	[0.116]		
other organization (distance <= 1 hour)	0.256**	[0.129]		
other organization (distance > 1 hour)	0.236**	[0.103]		
main technical field (reference group: chemicals & pharmaceuticals)				
electricity & electronics	0.003	[0.174]	-0.340***	[0.109]
instruments	0.218	[0.175]	-0.392***	[0.119]
process engineering	0.257*	[0.150]	-0.273***	[0.102]
mechanical engineering	0.190	[0.149]	-0.238**	[0.100]
consumer goods & civil engineering	0.283	[0.195]	-0.323**	[0.147]
research time (reference group: less than 1 man month)				
1 to 3 man months (mm)	-0.526***	[0.189]	0.349***	[0.097]
4 to 6 man months	-0.631**	[0.262]	0.657***	[0.106]
7 to 12 man months	-1.185**	[0.469]	0.919***	[0.115]
more than 13 man months	-0.632	[0.400]	1.348***	[0.112]
idea further developed in R&D project	-0.572***	[0.160]		
1 to 3 mm * further developed	0.431*	[0.237]		
4 to 6 mm * further developed	0.408	[0.305]		
7 to 12 mm * further developed	1.096**	[0.497]		
> 13 mm * further developed	0.157	[0.436]		
status employee-inventor	-0.511***	[0.156]		
type of the organization: firm	-0.281	[0.205]	0.760***	[0.166]
financial resources: internal funds	-0.384**	[0.163]		
PCT application filed			0.181***	[0.070]
number of claims			0.010**	[0.004]
lambda			-0.561**	[0.274]
Constant	-2.385**	[1.174]	1.744***	[0.287]
Observations	2542			
Chi2-test	chi2(29) = 274.32			

Standard errors in brackets / * significant at 10%; ** significant at 5%; *** significant at 1%

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APPENDIX

Table A1: Ordered probit and OLS analysis of the asset value of patents (N = 2,542)

	ordered probit	OLS
	asset value	asset value
leisure time invention (dummy)	0.360***	0.529***
	[0.083]	[0.128]
age of the inventor	0.006***	0.009***
	[0.002]	[0.003]
level of education (reference group: high school diploma or less)		
university studies	0.051	0.084
	[0.065]	[0.097]
doctoral/post doctoral studies	-0.030	-0.038
	[0.073]	[0.109]
main technical field (reference group: chemicals & pharmaceuticals)		
electricity & electronics	-0.218***	-0.343***
	[0.073]	[0.108]
instruments	-0.239***	-0.369***
	[0.079]	[0.119]
process engineering	-0.145**	-0.240**
	[0.067]	[0.101]
mechanical engineering	-0.146**	-0.213**
	[0.068]	[0.102]
consumer goods & civil engineering	-0.164*	-0.281**
	[0.091]	[0.137]
research time (reference group: less than 1 man month)		
1 to 3 man months	0.214***	0.292***
	[0.060]	[0.087]
4 to 6 man months	0.413***	0.589***
	[0.064]	[0.094]
7 to 12 man months	0.581***	0.857***
	[0.073]	[0.109]
more than 13 man months	0.833***	1.260***
	[0.071]	[0.103]
type of the organization: firm	0.432***	0.670***
	[0.105]	[0.153]
PCT application filed	0.126***	0.185***
	[0.047]	[0.070]
number of claims	0.006**	0.010***
	[0.003]	[0.004]
Constant		1.899***
		[0.266]
Observations	2542	2542
R-squared		0.092
Pseudo R2	0.025	

Robust standard errors in brackets / * significant at 10%; ** significant at 5%; *** significant at 1%

Table A2: Treatment-effects model, self-employed inventors (free inventors) and inventors who work for research institutes or universities excluded (N = 2,342)

	treatment-effects model			
	probit		OLS	
	leisure time invention		asset value	
leisure time invention (dummy)			1.401**	[0.663]
age of the inventor	0.109*	[0.057]	0.009**	[0.004]
age of the inventor (squared)	-0.001*	[0.001]		
level of education (reference group: high school diploma or less)				
university studies	-0.108	[0.139]	0.121	[0.109]
doctoral/post doctoral studies	-0.194	[0.165]	0.014	[0.120]
high intrinsic motivation	0.009	[0.093]		
employee mobility	-0.034	[0.101]		
current inventive output	0.020*	[0.011]		
type of interaction				
own organization (distance <= 1 hour)	-0.305***	[0.101]		
own organization (distance > 1 hour)	0.031	[0.120]		
other organization (distance <= 1 hour)	0.221	[0.144]		
other organization (distance > 1 hour)	0.214*	[0.113]		
main technical field (reference group: chemicals & pharmaceuticals)				
electricity & electronics	0.009	[0.181]	-0.314***	[0.113]
instruments	0.221	[0.189]	-0.386***	[0.127]
process engineering	0.267*	[0.159]	-0.249**	[0.107]
mechanical engineering	0.168	[0.159]	-0.206**	[0.104]
consumer goods & civil engineering	0.300	[0.207]	-0.294*	[0.153]
research time (reference group: less than 1 man month)				
1 to 3 man months (mm)	-0.651***	[0.211]	0.381***	[0.102]
4 to 6 man months	-0.599**	[0.289]	0.648***	[0.112]
7 to 12 man months	-0.913*	[0.482]	0.903***	[0.121]
more than 13 man months	-0.479	[0.410]	1.380***	[0.119]
idea further developed in R&D project	-0.569***	[0.168]		
1 to 3 mm * further developed	0.542**	[0.259]		
4 to 6 mm * further developed	0.371	[0.332]		
7 to 12 mm * further developed	0.824	[0.511]		
> 13 mm * further developed	-0.011	[0.452]		
financial resources: internal funds	-0.482***	[0.183]		
PCT application filed			0.169**	[0.074]
number of claims			0.009**	[0.005]
lambda			-0.445	[0.322]
Constant	-3.379**	[1.437]	2.405***	[0.236]
Observations	2342			
Chi2-test	chi2(28) = 249.29			

Standard errors in brackets / * significant at 10%; ** significant at 5%; *** significant at 1%