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On the trail of the intangible: a theoretical and empirical investigation of innovations and patents in Germany in the years 2006-2019

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ABSTRACT

Objective: We want to better understand what incentives firms to pursue innovations. For this purpose, we set up a new intertemporal principal-agent model. We then proceed to empirically assess the determinants of innovation activities unfolded by German firms between 2006 and 2019 and to also look at the causal factors – related to innovation activities – for the occurrence of patent registration in Germany.

Research Design & Methods: In the theoretical part, we make use of intertemporal optimization tools based on the principal-agent model (PAM). In the empirical part, we apply the so-called DuPont decomposition and non-linear regression techniques.

Findings: It seems that investment activities in conjunction with product innovations are the major determinants of innovation intensity. The latter (and other innovation related variables) in turn, is (are) responsible for the dynamics of patent registration in Germany.

Implications & Recommendations: Our results highlight the importance of smart reward systems in R&D departments in order to incentivize innovative activities. Our findings also point at the significance of a patent regulation friendly to the innovator.

Contribution & Value Added: Our findings deliver a new foundation of innovation activities based on an intertemporal principal agent approach which is confirmed by the empirical facts in the case of Germany.

Article type:	research article
Keywords:	innovation economics; principal-agent model; DuPont decomposition; non-linear regression
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INTRODUCTION

Germany is estimated to spend 176, 1 billions of EUR for innovations in 2022 (Handelsblatt February 1, 2022). Although it spends only about 3.2% of its GDP to R&D, it is listed fourth in the worldwide ranking of innovations (Handelsblatt January 20, 2022). Germany also stands out with regard to the number of yearly patent registrations, presently being the world's number two (ibid). Good reasons to investigate the German innovation story more in depth.

The ambition/objective of this contribution is twofold: (i) in the theoretical part of the paper, it is our purpose to understand better the economic logic of innovations on the firm level. To that end, we go back to the principal agent model (Burr 2017; Richter & Furubotn, 1999) which has proven to be so successful in economics/entrepreneurial science. Management and owners of the firm have different interests: while the first aims at a high compensation for its effort, the latter is primarily concerned, for example, with the growth of the firm. Owners cannot directly observe the level of effort of the management (asymmetric information), but they do can evaluate the result of the managements effort. Raising productivity, it seems, can serve both interests best: it is conducive to the growth of the firm, but it also enhances the possible compensation of management and employees.

We have extended the original (see, for example, Richter & Furubotn, 1999) most simple (no uncertainty, no adverse selection, no moral hazard) one-period principal-agent-model (PAM) to a two-periods or likewise intertemporal optimization approach – in the tradition of Frankel and Razin (1984) – which enables us to demonstrate the productivity raising effect of innovations. What matters here is not the absolute size of innovations, but their relative magnitude, i. e., the intensity of innovations: this ratio is often proxied by expenditures on innovations per unit of total firm's revenue. We will show that the productivity raising effect tends to be the larger, the higher the chosen innovation intensity is, c. p. The approach has to be intertemporal because the "decision to innovate" taken in the present involves a reallocation of resources whose benefits can hardly be reaped before the future arises.

In the empirical section (ii), we want to inquire empirically significant determinants of the innovation intensity in Germany. The data stem from the "ZEW Innovationserhebung 2021" following the method of the "Mannheimer Innovationspanel – MIP" and they cover the years 2006-2019. At the very start, we make use of the so-called DuPont decomposition technique. This method is "borrowed" from finance (Baumann, 2014; Kasik & Snapka, 2020), where "DuPont decomposition (is well known and, the author) is typically used … to further break down net operating surplus into its underlying components: returns on invested capital – or net operating surplus over net capital stock, which can be broken down further into profit margins on sales and capital turnover – and capital-to-output ratios" (McKinsey, 2019, p. 14). In our application, we will further break down "innovation intensity" into its underlying components. Thereafter, we test the impact of a high innovation intensity on the evolution of new knowledge, as it becomes evident through the registration (or likewise "production") of patents, as the most visible signal for new knowledge created by means of several non-linear regressions.

The rest of the paper is organized as follows: after this introduction, we give a brief review on related literature in section 2. In section 3, we first present our theoretical research methodology. Thereafter, we suggest a two-step empirical approach: DuPont decompositions of various stages and a number of non-linear regression analyses building on the former. Section 4 presents the results of our empirical investigations and discusses their relevance. Section 5 concludes and offers some scope for a future research on our topic. A flow-of-funds exercise for the transactions involved in the intertemporal PAM is located in the annex.

LITERATURE REVIEW

There is a great abundance of literature on the subject of innovations/patents. Broadly speaking, this literature can be categorized by the criteria of exogeneity vs. endogeneity: When we think of Schumpeter's pioneering entrepreneur or of economic policies labelled "innovation initiatives" to boost innovative investment, innovations are seen as a more or less exogenous variable. This strand of literature is not relevant for our subject. If taken instead as endogenous, innovations/patents may be regarded as a "natural" outcome of competition between firms (or even countries on the international level). But already on the firm level, innovations and the "production" of patents should result from implicit or explicit contracts between involved interest groups/stakeholders and are hence accessible to the use of PAM. Among the many relevant PAM applications in the area of innovations, Gang (2021), Taniguchi & Thompson (2018) and Chen *et al.* (2021) figure prominently.

As we suggest the key role of "innovation intensity" in both our own theoretical and empirical research, we came across the papers of Benazzouz (2019), Urbaniec (2019), Bigos and Michalik (2020) and of Kaszowska-Mojsa (2020). Complementary to Bigos and Michalik (2020), we go beyond the simple absolute record in the implementation of marketing (organizational, product, etc.) innovations, relying the analysis strictly on relative figures, such as "innovation intensity". Kaszowska-Mojsa (2020) deserves recognition for differentiating between persistent innovators, occasional innovators, and challengers. She has studied empirically the probability of implementing innovations which are affected by both supply side and demand side factors. Benazzouz (2019) puts some emphasis in making clearer the meaning, the content and the dimensions of "innovation intensity" (such as frequency, degree and internationalisation of innovations). Urbaniec (2019) finds that innovation activities and competitiveness are necessarily interrelated: competitiveness spurs innovation intensity, but innovation intensity also enhances competitiveness. Many recent publications can be found which investigate the determinants of innovation intensity in cross-section or country studies (Falk & Hagsten, 2021; Thang *et al.*, 2021).

Goel and Zhang (2019) discover the possibility to hedge against political and economic uncertainties by innovating and, later on, patenting (Goel & Nelson, 2021). The traditional view, according to which, in the short-run, innovations in production processes bring in uncertainty for large parts of the employees is here contrasted with the observation that the long-run likelihood of firms' survival crucially hinges upon its capability to raise innovations and thereby to foster growth of the firm. Only surviving firms, in turn, can guarantee employment. As a result, the short-run trade-off between employment and innovations is softened. These positive implications of innovations for the employees of the firm are a key aspect of our model, too.

The usage of the Du Pont decomposition technique outside finance is rare, but fruitful: a recent study (McKinsey, 2019) has yielded far-reaching insights into the fall of the US labour share by means of this tool. There is a long-lasting tradition of investigating the "production" of patents, for example with regard to economic growth (Pena-Sanchez, 2013), the role of academic institutions (Coronado Guerrero, 2017) or international cooperation (Klauß, 2019).

Empirical investigations on innovations and patents in Germany are not often to find and mostly dedicated to specific industries (pharmaceuticals, automobile industry, ICT etc., see Behrens and Viete, 2020). Koppel *et al.* (2017) investigate the existence of a sort of "patent production function", comparable to our own approach. The authors report that R & D expenditures and employment of STEM (Smart energy storage and energy management service) graduates to successful patent applications.

In light of the cited literature, our own contribution is novel in as far as it combines a presumably new theoretical foundation for innovations with a two-step empirical validation.

RESEARCH METHODOLOGY

The research methodology chosen consists of two parts: in the first one, we develop a theoretical explanation for innovations in a two-periods-optimization horizon, extending the traditional principal agent model (PAM). In the second part, we test empirically the forces which tend to raise innovation intensity in German firms (2006-2019). We then investigate those variables related to innovation which presumably incentivize patent registrations in Germany. More information on the methodological steps made (optimization tool, variables used, data description, quantitative/econometric design, etc.) in detail will be provided in the following sub-sections.

An intertemporal principal-agent model of innovation

PAM already fits quite well when it comes to explain the conflicting incentives[1] within a R&D department or likewise between the R&D section and the management of the company (Burr, 2017). But it also helps to understand the overall motivation for innovation activities on the firm level. The intertemporal theory of the balance of payments (Frenkel & Razin, 1984) is a vehicle to introduce the two-period optimization perspective into the principal-agent model.

We have two periods of observation. Assume an agent (management of the firm) who is provided with a fixed budget given to him by the principal (owner of the firm) before production starts. The principal expects the agent to return the corresponding budget at the end of the production and sales period. Capital costs (return on capital), costs for imported inputs, etc. are neglected here in order to keep things simple. The agent will spend the budget in period 1 totally for wages and organize the production and the sales of a single good. The revenues generated by sales of the good are in equilibrium as large as the wage bill and so high enough to return the budget to the principal

[1] The principal seeks to maximize profits, but he can only do so by respecting both the incentive compatibility and the participation conditions of the agent.

at the end of period 1. In period 2, this process is replicated. So far, the base scenario. There is neither any productivity gain nor growth of the firm.

As an alternative, the agent may now save in period 1 part of the budget which in principle is designated to wages and then invest this amount of money, preferably into an innovation. One may think of the innovation in two ways: either the good is now produced with a higher quality at a given size of production (this would equal a product innovation) or the good is produced now, albeit with an unchanged quality, with a larger size of production (this would equal a technological innovation). The lower sales of the good in period 1, however, are now not high enough to cover the budget extended by the principal to the agent at the beginning of period 1. So the principal becomes now – whether he likes it or not – a lender vis-à-vis to the agent. Employees accept the lower wages or likewise forced savings in period 1 only because the agent promises to compensate them with a significantly higher level of consumption in period 2 than the one experienced in period 1. At the beginning of period 2, the principal now extends a larger budget to the agent as in period 1. The additional budget components are due to the forced savings plus the corresponding interest rate income the agent has to pass on to the employees. The principal expects to receive this extended budget back at the end of period 2, plus the implicit credit he extended in period 1 to the agent, including interest payments which now accrue to him. These interest payments can be regarded as a return on the credit (capital) extended by the principal to the agent.

The key control variable for the agent is the amount of innovative investment: he must generate a surplus in period 2 in order to fully compensate both his employees and the principal for the wage losses/credit payments they had to afford/extend in period 1, taking into account the respective time preference rate of workers and of the principal. To achieve this goal, obviously a critical marginal return on the innovative investment must be realized. The key control variable for the principal is the interest rate, which can be interpreted as a minimum fixed return on capital, which was purposely neglected in the base scenario: if it is "too low", the agent and the employees profit "too much" from the innovative investment activities and being a principal is sub-optimal. If the interest rate is "too high", the principal risks the default on the credit he has extended in period 1 to the agent and the innovation, and hence the firm's growth, cannot prevail.

The formal rationale for innovative investment

The budget delivered by the principal to the agent before productions starts in period 1 is a fixed lump sum which the agent distributes among the employees for their consumption only. Hence, there is no wilful saving on the part of the employees:

$$\overline{Y}_1 = C_1 \tag{1}$$

After production period 1 is completed, the agent returns the fixed sum to the principal. The principal's savings ratio is one in each period. So far, the base line scenario. This situation changes, once the agent diverts in period 1 some money from the principal's budget which he invests into an innovation:

$$\overline{Y}_1 = C_1 + I^n \tag{2}$$

$$C_1 = \overline{Y}_1 - I^n \tag{3}$$

$$S_1 = I^n \tag{4}$$

Employees hence have now to renounce on part of their consumption in period 1 according to (3) so that the agent can pursue an innovative investment strategy. Forced savings are, by definition, equal to investment expenditures (4). The principal becomes a lender to the agent at the end of period 1. Notice that actual production and income generated by the employees declines proportionally to their reduced consumption possibilities. In Figure 1, we identify the fixed incomes on the vertical (period 2) as well as on the horizontal (period 1) axis: $\overline{Y}_1 = \overline{Y}_2$. These two fixed incomes are given when there is no investment and hence no investment return is to be expected. They define the "Resource-Endowment Point" (REP). The "investment yield curve" is concave and it has its origin in the REP. It rises and turns counterclockwise and up towards the vertical axis. Its slope is meant to be the marginal gross return on investment (see below).

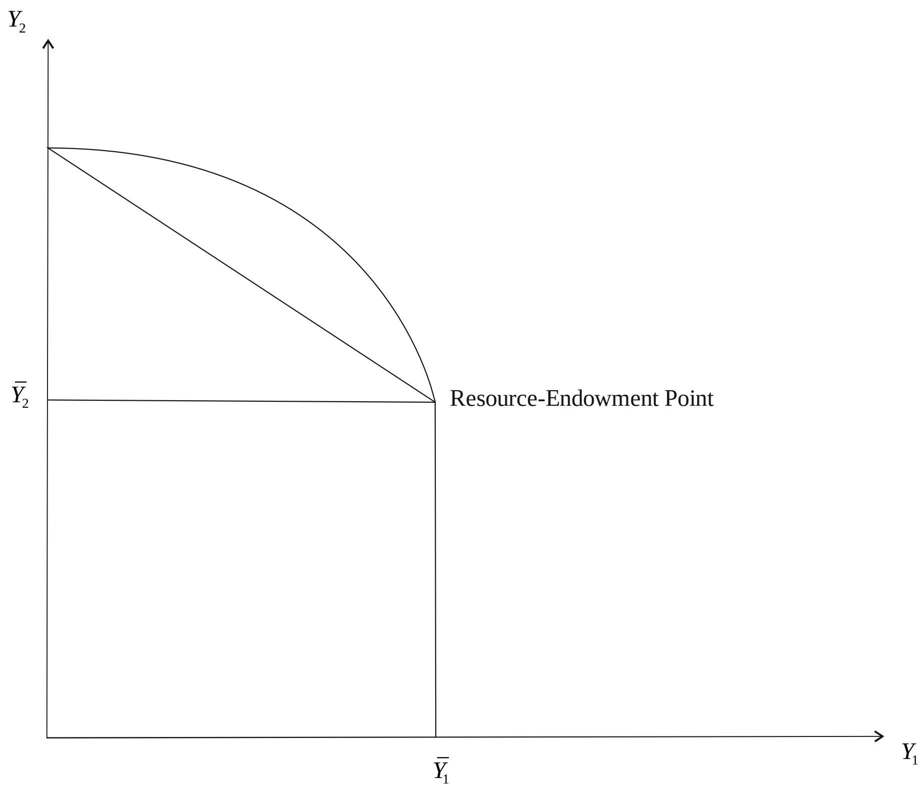

Figure 1. The investment yield curve
Source: own elaboration.

The new (gross) income generated in period 2 now amounts to:

$$Y_2 = \overline{Y}_2 + F(I^n) \tag{5}$$

With: $F(I^n)$ = gross return on investment and I^n = net expenditures on investment. Notice that the new income Y_2 is not what the agent owes to the principal at the end of period 2 (see below). By definition, the net return on investment, π, equals:

$$F(I^n) - I^n(1 + r) = \pi = \text{net return on investment (capital value)} \tag{6}$$

The problem to be solved by the agent consists in maximising the net return on investment:

$$\text{Max! } \pi = F(I^n) - I^n(1 + r) \tag{7}$$

Where π stands for the capital value of the investment. Derivating this equation with respect to net investment (I^n) yields:

$$\frac{\partial \pi}{\partial I^n} = F'(I^n) - (1 + r) = 0;\ F'(I^n) = 1 + r \tag{8}$$

Hence, the marginal gross return on investment must in the optimum equal the interest rate factor. Notice that the interest rate factor has to have a negative impact on π, ceteris paribus:

$$\frac{\partial \pi}{\delta(1+r)} = -I^n < 0 \tag{9}$$

Consumption (employees and agents) behaviour

Households face an intertemporal budget constraint which, in the case of the first, base line scenario (no investment), reads:

$$C_1 + \frac{C_2}{(1+r)} = \overline{Y}_1 + \frac{\overline{Y}_2}{(1+r)} = W \tag{10}$$

$$C_2 = (1 + r)(\overline{Y}_1 - C_1) + \overline{Y}_2 = W \tag{11}$$

Actual consumption together with the present value of future consumption must not exceed the corresponding sum of income variables (which equals total wealth, W).

$$C_1 = 0\,;\; C_2 = (1+r)\overline{Y}_1 + \overline{Y}_2 \quad (12)$$

$$C_2 = 0;\; C_1 = \overline{Y}_1 + \frac{\overline{Y}_2}{(1+r)} \quad (13)$$

The position of the intertemporal budget constraint is determined by income, its increase by the interest rate factor: $[\tan(\alpha) = -(1+r)]$.

The utility function is standard and has the following form:

$$U = u(C_1) + \beta u(C_2); \beta = \text{discount factor and } 0 < \beta < 1 \quad (14)$$

A totals differential of this equation leads to:

$$dU = u'(C_1)dC_1 + \beta u'(C_2)dC_2 = 0 \quad (15)$$

$$\frac{dC_2}{dC_1} = -\frac{u'(C_1)}{\beta u'(C_2)} \quad (16)$$

The slope of the intertemporal indifference curve, must, hence, be in the optimum identical with the slope of the intertemporal budget constraint, – (1+r).

Looking now more closely at our constrained maximization problem, the maximum of utility in both periods reads:

$$\max L = u(C_1) + \beta u(C_2) + \lambda\left[W - C_1 - \frac{C_2}{(1+r)}\right] \quad (17)$$

$$\left.\begin{aligned} \frac{\partial L}{\partial C_1} &= u'(C_1) - \lambda = 0 & (18)\\ \frac{\partial L}{\partial C_2} &= \beta u'(C_2) - \frac{\lambda}{1+r} = 0 & (19)\\ \frac{\partial L}{\partial \lambda} &= W - C_1 - \frac{C_2}{(1+r)} = 0 & (20) \end{aligned}\right\} \frac{u'(C_1)}{\beta u'(C_2)} = 1 + r$$

As a rather standard result, we achieve the equality of the interest rate factor, (1 + r), on the one hand and the ratio between the marginal consumption utility in the present and the (discounted) marginal consumption utility in the future, on the other hand.

In the second, investment scenario, the following budgeting equations must be fulfilled:

$$\overline{Y}_1 = C_1 - I^n \quad (21)$$

$$C_1 = \overline{Y}_1 - I^n \quad (22)$$

In the first period, consumption possibilities for the employees and the agent are constrained by the net investment activity of the agent which equals forced savings from the viewpoint of employees.

$$\overline{Y}_2 = C_2 - (\overline{Y}_1 - C_1)(1+r) - \pi \quad (23)$$

$$C_2 = \overline{Y}_2 + (\overline{Y}_1 - C_1)(1+r) + \pi \quad (24)$$

In period 2, employee’s and the agents consumption possibilities encompass three items: the budget extended by the principal at the beginning of period 2, the forced savings of period 1 times the interest rate factor, plus the net return on investment gained from innovative investment in period 1.

Solving the agents puzzle (investment plus consumption)

What a difference does it make when there happens to be not just an ordinary, but an innovative investment in period 1? In Figure 2, we have depicted a relatively steep investment yield curve. This can only occur in the case of an innovative investment. Otherwise, the investment yield curve must behave differently and run comparatively flat. The size of investment expenditures I^n is given by the distance, AB (or I = S). Given the negative sloped budget contraint line IH, a tangential point is reached in E, which determines equilibrium of income and production in period 2. Income has now the level Y_2. We observe a gross return on investment AE. Notice that the equilibrium for consumption is located in D (where the relevant budget constraint line denotes JK), because the distance ED is that part of production of period 2 which accrues to the principal. We realize that the capital value π (BF) of the innovative investment enables all households (employees plus the agent) to reach a higher consumption level in D than it would have been possible without the innovative investment (as for example in L which lies on the original budget constraint line). Notice that the new income Y_2 is obviously higher than it was before ($\overline{Y}_1$), a result which – at a given and unchanged degree of employment – points at the increase in (labor) productivity. The latter is a prerequistite for the growth of the firm, just as much as it is on the national level of any economy. $(Y_2 - \overline{Y}_2)/\overline{Y}_2$ can serve as a proxy for such a growth rate.

What is the impact of alternative interest rates? With a high interest rate charged by the principal, two outcomes appear possible: on the one hand, the probability for a default of the agent rises, ceteris paribus. On the other hand, a high interest rate forces the agent to find particularly productive and hence innovative investment opportunities, both to satisfy the claims of the principal, but also to be able to compensate the employees for the loss of welfare in period 1.

Discussion

(i) both employees and the agent have a strong interest in achieving innovative investments which can boost income of period 2 to so far unprecedented levels. The agent and the employees profit in direct proportionality to the (high) net capital value which (only) an innovative investment is capable to raise. This finding adds to the positive implications of innovations for employees already stressed in literature (see above). (ii) It is obvious that this concern is served best when the agent is able to achieve a high innovation intensity. This quota can be proxied by the ratio between expenditures on innovation ($I^n = S$) and the (original) level of revenues, $\overline{Y}_1$. Notice that "innovation intensity" will be the key variable in our empirical section, too. (iii) The principal does not profit from innovative investment directly, his net gain is just a modest interest income. He could do better, if he would share a part of the net capital value raised by the agent.[2] For that he would have to switch to a flexible contract with the agent. In the annex, we simulate a numerical flow of funds analysis with all transactions between the three players considered in our theoretical model.

RESULTS AND DISCUSSION

The available sector-specific data from the ZEW will be used for empirically testing the relevance of variables which possibly are the most relevant influencial factors on innovation intensity. In doing so, we can refer ourselves and the reader to other contributions in literature which (see Benazzouz, 2019; Bigos & Michalik, 2020; Kaszowska-Mojsa 2020; Urbaniec, 2019; and further papers cited therein) highlight the significance of innovation intensity for entrepreneurial success.

Unfortunately, the available informations/data on German firms do not allow for an investigation of the impact of governments patent policy on innovation activities. However, it is possible to empirically assess the reverse question, that is, to what extent innovation activities "produce" the registration of patents. In all of the mentioned analyses, we limit our scope to Germany and to the recent time period from 2006 to 2019 (14 observations). While the latter time span is more or less dictated by data availability, Germany is chosen in particular because of its long-history with patents and its outstanding innovation record.

[2] Notice the similarity of our modeling to the "sharecropping vs. fixed rent contracts in agriculture" literature. See Narayan *et al.*, 2019.

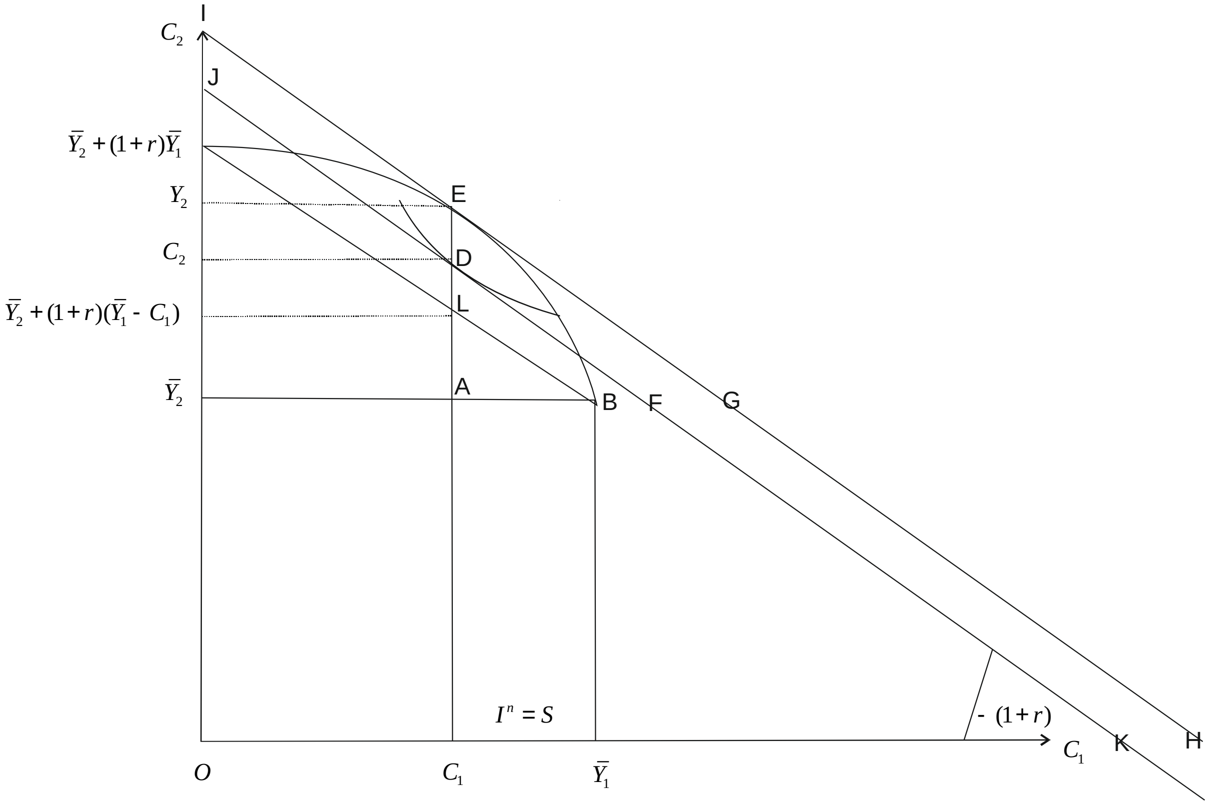

Figure 2. The optimal innovative investment
Source: own elaboration.

In this section, we intend to address the following two questions:

1. What does the empirical calibration of the DuPont decomposition yield with regard to the determinannts of innovation intensity (II)?
2. How is empirically the relationship between different proxies for innovation activities (such as expenditures on innovation, innovation intensity (II), innovative investment expenditures and/or R&D expenditures) on the one hand and patent registration (PR) on the other hand? This can be a sort of test for the existence of a "patent production function" by means of a non-linear regresion analysis.

DuPont decomposition

In the following, we conduct a two-step, a three-step and a four-step so-called „DuPont decompostion" (Borodin, 2021; Morris & Daley, 2017), a technique widespread in finance, to detect, in our case, the main determinants of innovation intensity (II).[3] The latter seems to be a key variable enabling firms to register patents, and, after that, to possibly reap the benefits of patents as (more or less) transitory monopolists in the sense of Schumpeter (1911).

Data Description

A huge data set is available thanks to the courtesy of the "Zentrum für Europäische Wirtschaftsforschung" (ZEW), Mannheim. Their research project, called "Kernindikatoren zum Inovationsverhalten von Unternehmen"[4] collects and systematically orders quantitative figures on the innovative behaviour of business firms in Germany (2006-2019). These firms belong to a sample

[3] This definition of *innovation intensity* follows ZEW (2021) and means expenditures on innovations per unit of total firm's revenue. How are "expenditures on innovations" related to "expenditures on R&D?" R&D implies the existence of a corresponding internal unit within the firm with permanent employees, a specific budget, etc. Expenditures for R&D are hence a part of the (aggregate) expenditures on innovations. The latter also include expenses for patents, licenses, external consulting, etc.

[4] Key indicators for innovative behaviour of firms.

encompassing both the production and the services sector. The project is sponsored by the "Bundesministerium für Bildung und Forschung"[5] (Berlin). The purpose of the project is to raise quantitative data on the innovative activities in the busines site. All absolute figures have the dimension Billions of Euro, all shares are meant to be percentage values.

Two-step DuPont decomposition

Under this approach, we break down innovation intensity (II) into two firm-specific ratios as follows:

II = EOIPUOIIE x IIEPUOTFR

Where all the following ratios have the dimension of percentage points:

EOI = Expenditures on innovations;
II = Innovation intensity = Expenditures on innovations per unit of total firms revenue[6]
EOIPUOIIE = Expenditures on innovations per unit of innovative investment expenditures
IIEPUOTFR = Innovative investment expenditures per unit of total firms revenue[7]

Example for 2019:	**Example for 2010:**	**Example for 2006**:
II = 3.3	II = 2.6	II = 2.8
EOIPUOIIE = 0.04	EOIPUOIIE = 0.031	EOIPUOIIE = 0.029
IEEPUOPIR = 82.508	IEEPUOPIR = 83.2	IEEPUOPIR = 98.0

Growth rates (G) of the two-step DuPont Decomposition:

GII = GEOIPUOIIE + GIEEPUOPIR

Growth rates (2019-2010)	**Growth rates (2010-2006)**
GII = -7.1	GII = 26.9
GEOIPUOIIE = 29	GEOIPUOIIE = 6.9
GIIEPUOTFR = - 2.1	GIIEPUOTFR = - 14

Four-step DuPont decomposition

Under this decomposition, II is now a function of the following three indicators:

II = EOIPUOIIE x IEEPUOPIR x PIRPUOTFR

where:

EOI = Expenditures on innovations;
II = Innovation intensity = Expenditures on innovations per unit of total firms revenue;
EOIPUOIIE = Expenditures on innovations per unit of innovative investment expenditures;
IIEPUOTFR = Innovative investment expenditures per unit of total firms revenue = Innovative investment expenditures per unit of product innovations revenue x product innovations revenue per unit of total firms revenue;
IEEPUOPIR = Innovative investment expenditures per unit of product innovations revenue;
PIRPUOTFR = Product innovations revenue per unit of total firms revenue.

[5] The Federal Ministry for Research and Education in Germany.
[6] Notice that this definition of innovation intensity is rather standard. It combines information from the input *and* from the output level of the firm. Therefore, it will follow this logic, when we make use of indicators which possess the same property in the above DuPont decomposition.
[7] While expenditures on innovations encompass all sort of spending related to innovations, innovative investment expenditures only (and strictly) apply to *investment* into innovations. Together with the information of footnote 1, we achieve: Expenditures on innovations = expenditures on R&D + specific budget of R&D department = innovative investment expenditures + other expenditures on innovation.

Example for 2019:	Example for 2010:	Example for 2006:
II = 3.3	II = 2.6	II = 2.8
EOIPUOIIE = 0.04	EOIPUOIIE = 0.031	EOIPUOIIE = 0.029
IEEPUOPIR = 5.946	IEEPUOPIR = 5.497	IEEPUOPIR = 5.435
PIRPUOTFR = 13.876	PIRPUOTFR = 15.136	PIRPUOTFR = 18.03

Growth rates (G) of the three-step DuPont Decomposition:

GII = GEOIPUOIIE + GIEEPUOPIR + GPIRPUOTFR

Growth rates (2019-2010)	Growth rates (2010-2006)
GII = 26.9	GII = -7.1
GEOIPUOIIE = 29	GEOIPUOIIE = 6.9
GIEEPUOPIR = 8.2	GIEEPUOPIR = 1.1
GIRPUOTFR = -10.3	GIRPUOTFR = -0.9

Four-step DuPont decomposition

Under this decomposition, II is a function of the following four indicators:

II = EOIPUOIIE x IEEPUOPIR x PIRPOUMI x MIPUOTFR

where:

EOI = Expenditures on innovations;
II = Innovation intensity = Expenditures on innovations per unit of total firms revenue;
EOIPUOIIE = Expenditures on innovations per unit of innovative investment expenditures;
IEEPUOPIR = Innovative investment expenditures per unit of product innovations revenue;
PIRPUOTFR = Product innovations revenue per unit of total firms revenue = Product innovations revenue per unit of market innovations revenue x market innovations revenue per unit of total firms revenue;
PIRPUOMI = Product innovations revenue per unit of market innovations revenue
MIPUOTFR = Market innovations revenue per unit of total firms revenue[8]

Example for 2019:	Example for 2010:	Example for 2006:
II = 3.3	II = 2.6	II = 2.8
EOIPUOIIE = 0.04	EOIPUOIIE = 0.031	EOIPUOIIE = 0.029
IEEPUOPIR = 5.946	IEEPUOPIR = 5.497	IEEPUOPIR = 5.435
PIRPUOMI = 4.724	PIRPUOMI = 4.139	PIRPUOMI = 5.143
MIPUOTFR = 2.9	MIPUOTFR = 3.6	MIPUOTFR = 3.5

Growth rates (G) of the four-step DuPont Decomposition:

GII = GEOIPUOIIE + GIEEPUOPIR + GPIRPOUMI + GMIPUOTFR

Growth rates (2019-2010)	Growth rates (2010-2006)
GII = 26.9	GII = -7.1
GEOIPUOIIE = 29	GEOIPUOIIE = 6.9
GIEEPUOPIR = 8.2	GIEEPUOPIR = 1.1
GPIRPUOMI = 14.1	GPIRPUOMI = -19.5

[8] What is the difference between „product innovations" on the one hand and "market innovations" on the other hand? According to ZEW (2021), market innovations encompass only new and/or significantly improved products (including services), which were firstly introduced by firms on the market. As opposed to this, product innovations can be market innovations, but they may include also non-novelties, to say so, which are labelled "imitative innovations". This implies also that there is no single category for "imitations" alone. Indirectly spoken, imitations' weight or importance should be the higher, the higher the ratio between product innovations and market innovations is.

GMIPUOTFR = -24.4 GMIPUOTFR = 4.4

Results achieved from the DuPont decomposition technique and discussion:

- The two subperiods available (2006-2010; 2010-2019) are obviously completely different with regard to the dynamics of innovation intensity: while we observe a decline (negative growth rate) in the first, shorter period, there is a significant increase (positive growth rate) in the second, longer period.
- Looking at the main driving forces for the growth of innovation intensity, the growth rate of expenditures on innovations per unit of innovative investment expenditures figures prominently. Next come the growth rate of innovative investment expenditures per unit of product innovations revenue and the growth rate of product innovations revenue per unit of market innovations.
- So, in essence, innovative investment expenditures and product & market innovations seem to dominate the picture of influential factors for the achievement of a high innovation intensity. This comes very close to our theoretical explanation from above, where the decision of the agent to renounce on consumption/to invest "forced" savings in the present period in exchange for a higher income and welfare in the next, future period, highlights the relevance of innovations. Such an innovative firm also resembles to Joseph Schumpeter's view of competition, where the pioneering innovator and his imitators play the key roles (ibid, 1911).
- And yet, the data available to us are not quite capable to directly measure the relevance of imitations. Only a clear differentiation between innovations and imitations would in principle allow to empirically follow the footsteps of Schumpeter. For that, it would be indispensable to be able to distinguish conceptually between innovative investment expenditures and imitative investment expenditures.

Non-Linear Regression Analysis

The relationship between patents and innovations is diverse and far from being clear. Patents are sometimes seen as a proxy for measuring innovations (Burhan *et al.*, 2017), patents may protect inventions and innovations against mental theft (Belleflamme & Bloch, 2013), patents are also assessed as a key source of innovations (Behrmann, 2007), at the same time, it is said that inventions lead to innovations and both can lead, in the end, to patents (Burr, 2017).

When it comes to empirically investigate the relationship between innovations and patent registration, (at least) two different approaches are feasible: on the one hand, one may look after the effect of patent registration activity on innovations. This first question is somehow uneasy to answer because patent registration obviouosly triggers licenses and licenses, in turn, will have a strong impact on imitation activities. Hence, a typical "identification problem", well known since long in econometrics, arises. However, one may also, conversely, be interested in the effect of innovation activity on the dynamics of patent registration. Since we already have an idea, what empirically are – according to the above DuPont decomposition – the main determinants of innovation intensity on the firm level, we decided to investigate the latter puzzle, that is the impact of innovation intensity and of closely related varaibles on patent registration.

Data Description

The data for expenditures on innovation, innovative investment expenditures, for R&D expenditures and for innovation intensity (see above) stem from the "Kernindikatoren zum Inovationsverhalten von Unternehmen", a document edited by ZEW (2021). They cover the period from 2006 to 2019. The data on patent registration activities of private firms in Germany, also for the period 2006-2019 (n = 14 observations), come from the "Deutsches Patent- und Markenamt (2020): "The number of patent registrations in Germany between 2000 and 2019".

Based on the above described data set, we have regressed total patent registration (absolute numbers) of private firms from Germany (2006-2019) alternatively on (in that order): expenditures on innovation, innovation intensity, innovative investment expenditures, and relative R& D expenditures (see Figures 3 through 6). More precisely, we tested/estimated the equation:

$$X_t = a_i + b_i \ln Z_{it} \tag{25}$$

with

$$X_t = \text{Patent registration (Germany, 2006} - \text{2019)} \qquad (26)$$

Z_{1t} = Expenditures on innovation; Z_{2t} = Innovation intensity; Z_{3t} = Innovative investment expenditures; Z_{4t} = R&D expenditures as a percentage of total investment expenditures.

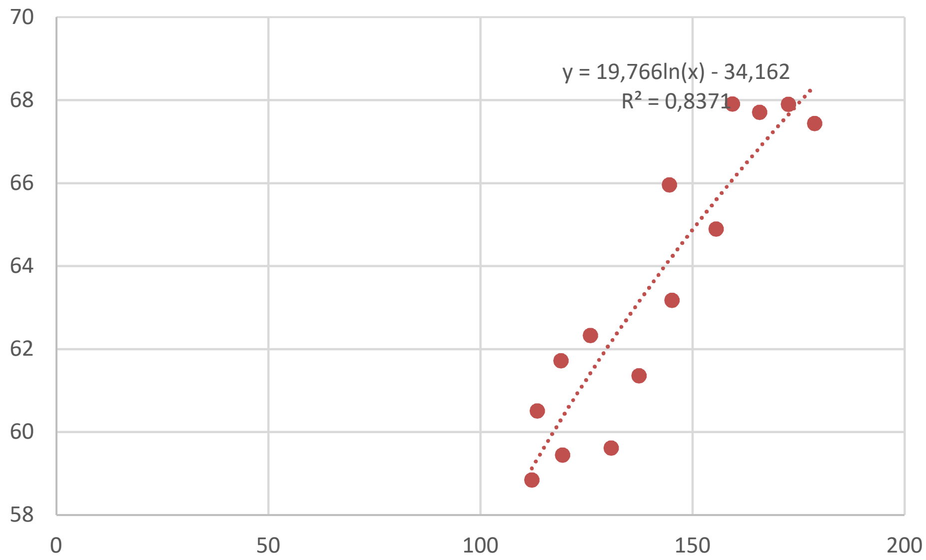

Figure 3. Patent registration as a function of expenditures on innovation (Germany, 2006-2019)
Source: own elaboration.

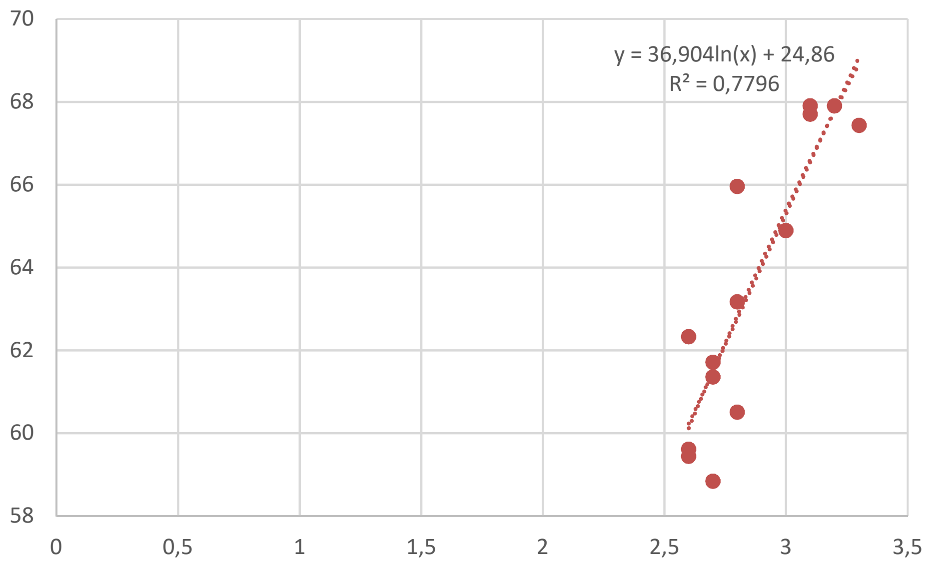

Figure 4. Patent registration as a function of innovation intensity (Germany, 2006-2019)
Source: own elaboration.

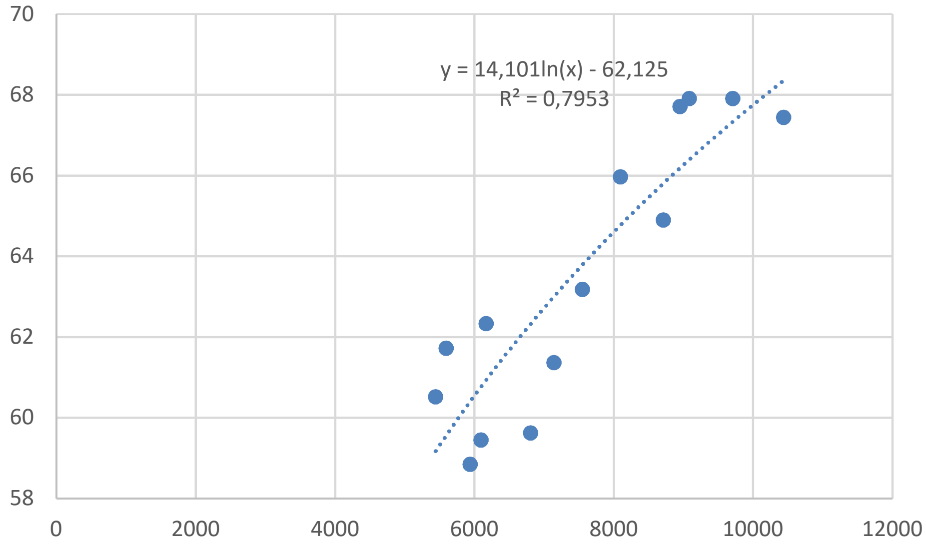

Figure 5. Patent registration as a function of innovation intensity (Germany, 2006-2019)
Source: own elaboration.

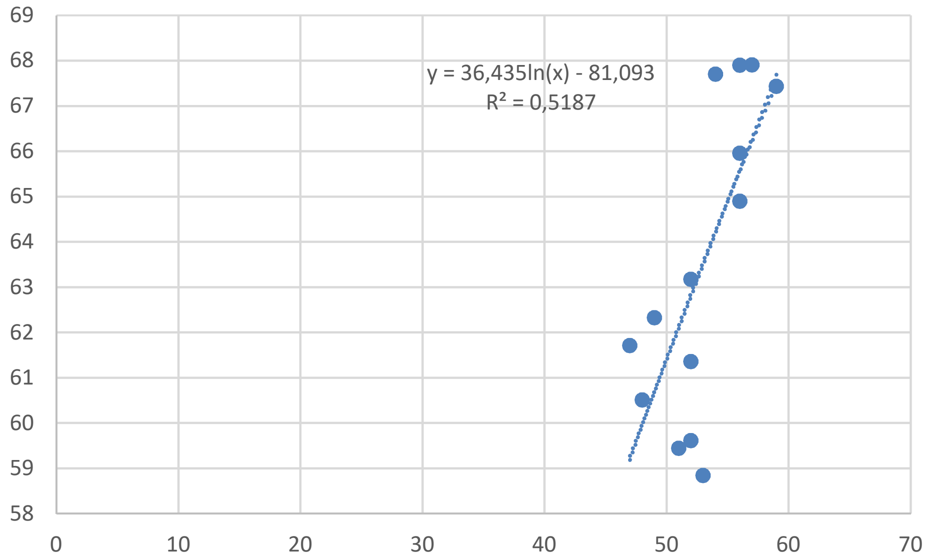

Figure 6. Patent registration as a function of R&D expenditures as a percentage of total investment expenditures (Germany, 2006-2019)
Source: own elaboration.

Results and discussion of the non-linear regression analysis

It turns out that all four alternative explanations for the behavior of patent registration – namely expenditures on innovation, innovation intensity, innovative investment expenditures and relative R&D expenditures – prove to be quite useful in our simple non-linear regression analysis as explanatory variables. The fact that a semi-logarithmic form of the estimation equation performs best points at the presumed declining marginal returns of innovative investment (see Burr 2017). The R^2 achieved is almost always in the neighborhood of 80 percent (see Figures 3 through 6). All parameter estimates, with the exception of $\hat{a}_4$ (10%) are significant at the 1 % probability of error level:

$$\hat{a}_1 = -34{,}162^{***};\ \hat{b}_1 = 19{,}766^{***}\ \hat{a}_2 = -24{,}186^{***};\ \hat{b}_2 = 36{,}904^{***}\ \hat{a}_3 = -62{,}125^{***};\ \hat{b}_3 = 14{,}101^{***}$$
$$(-2{,}746);\quad (7{,}852)\quad (-4{,}180);\quad (6{,}515)\quad (-3{,}376);\quad (6{,}827)$$

$$\hat{a}_4 = -81,093^{*};\ \hat{b}_4 = 36,435^{***}$$
$$(-2,017); \qquad (3,596)$$

Looking at the size of the parameter estimates, we can see that innovation intensity ($\hat{b}_2 = 36,904^{***}$) seems to comparatively have the strongest impact on patent registration, ceteris paribus.

CONCLUSIONS

In this paper, we have analyzed both theoretically and empirically innovations, patents and how their reciprocal relationsship possibly functions. The principal agent model (PAM), once it is further developed to an intertemporal approach, serves good to better understand the motivation and the economic effects generated by innovation seeking and investing agents. It also helps to identify the key control variables of the principal, which is the interest rate, and of the agent, which is the chosen innovation intensity.

In our empirical section, we have in the first place made use of the DuPont decomposition in order to detect – for the time span of 2006-2019 – the determinants of innovation intensity among German firms of all kind of sectors. Notice that hereby we also contribute to a broader application of the DuPont decomposition technique. Looking at the derived main driving forces for the growth of innovation intensity, the growth rate of expenditures on innovations per unit of innovative investment expenditures figures prominently. Next come the growth rate of innovative investment expenditures per unit of product innovations revenue and the growth rate of product innovations revenue per unit of market innovations revenue. Investment and product innovations seem to dominate the picture. This comes very close to Joseph Schumpeter's view of competition, where the pioneering entrepreneur succeeds via innovative investment and product innovations.

In the subsequent regression analysis, we tested for alternative explanations of the behaviour of patent registration – namely expenditures on innovation, innovation intensity, innovative investment expenditures and relative R&D expenditures. The fact that a semi-logarithmic form of the estimation equation performs best points at the presumed declining marginal returns of innovations (Burr 2017). The R^2 achieved is always in the neighbourhood of 80 percent, all (but one) estimated coefficients are significant at the 1% percent level of error likelihood.

These findings confirm earlier studies on the outstanding role of innovation intensity for the production of patents, as mentioned before in our brief literature review, but contradicts recent findings of Hernandez and Rueda Galvis (2021): … "that overconfidence arises in relation to competition when registering patents and not developing continuous improvement or innovation processes" (p. 154). These results, however, apply to emerging economies such as Colombia only and not to advanced economies such as Germany.

The limitations of our investigation are obvious. Just to mention three of them: (i) patents are an uncomplete measure of innovation (not all innovations are patentable for legal reasons; not all patentable innovations are patented by firms for strategic reasons). (ii) The available data are not (yet) quite capable to directly measure the relevance of imitations. Only a clear differentiation between the categories of innovations and of imitations would in principle allow us to more or less perfectly follow empirically the footsteps of Schumpeter. (iii) This would help us further to verify whether the Schumpeterian momentum still applies in a world of digitalisation and globalisation.

Theoretical implications of our paper can be found in the potential to further develop the PAM along the lines of our approach (intertemporal optimization, inclusion of the employees' perspective etc.). As far as managerial implications of our findings are concerned, our results highlight the importance of smart reward systems in R&D departments in order to incentivize innovative activities. As far as economic policy is concerned, there is no substitute for keeping markets open and to secure property rights.

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Appendix: A flow of funds analysis of transactions between principal, agent and employees

Period	Principal	Agent	Employees
t10	-100	100	80
		-20	
		-80	
t11	80	80	
		-80	
t20	-122	122	122
		-122	
t21	144	150	
	122	-144	
	22		
Balance	2	6	
		-6	6

Explanation: At the beginning of period 1, the principal gives 100 units to the agent. The agent divides these 100 units into 80 units which he pays to the employees and 20 units which he invests in an innovation. These 20 units can be taken as forced savings of the employees which are accustomed to a wage sum of 100 units. At the end of period 1, the agent receives the revenue from the sales of the good, produced by the employees. These sales amount to 80 units because we disregard from capital costs, management compensation, etc. The agent passes on 80 units to the principal. The difference to the 100 units, the principal extended to the agent at the beginning of period 1, can be understood as an implicit credit. At the beginning of period 2, the principal gives to the agent 122 units: 100 units as an equivalent to regular wages of 100 units and say 22 units as the return of forced savings, including interest payments (10%), to the employees. The agent passes these 122 units on to the employees. At the end of period 2, income and production reach a new level of 150 units due to the innovative investment of the agent in period 1. The agent returns 144 units to the principal: 100 units as an equivalent to the regular wage sum of 100 and 22 units as the return of forced savings of the employees plus another 22 units. These latter 22 units are a payment to cover the credit costs and include interest payments (2) of the implicit credit given earlier by the principal to the agent. The total balance for the principal is positive, but only by the margin of 2 units. The total balance for the agent is “ex aequo”, if he transfers his positive balance of 6 units to the group of employees to which he belongs not only way of his role of consumer, but also according to labor market classification.

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Conflict of Interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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