A quantitative approach of innovation

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Master IREN - Industries de Réseau et Economie Numérique

Chapter 2. The Measurement of Innovation

Issues and questions raised in this chapter :

- How to measure innovation ?
- How to measure the returns to innovation
  - Private returns
    - Productivity models
    - Firm market value models
  - Social returns to innovation - positive knowledge and R&D externalities
- The value of patent statistics
  - Information in patent documents
  - Knowledge production function
  - The value of patents - Quantity vs Quality !

1. Defining innovation

1.1. What is innovation ?

- Innovation is a continuous process
  - Firms constantly make changes to products and processes and collect new knowledge
- Schumpeter (1934) : economic development is driven by innovation through a **dynamic process** in which new technologies replace the old technologies $\Rightarrow$ « creative destruction ».
  - Radical innovations create major disruptive changes whereas incremental innovations continuously advance the process of change
- Schumpeter distinguishes **five types of innovations**
  - Introduction of new **products**
  - Introduction of new **methods of production**
  - Opening **new markets**
  - Development of new sources of **supply** for raw materials or other inputs
  - Creation of **new market structures** in an industry

1.1. What is innovation ?

- **The Oslo Manual** is a guide for collecting, reporting and using Data on Innovation. The fourth edition (2018) `https://www.oecd.org/science/oslo-manual-2018-9789264304604-en.htm` :
  - **An innovation** is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).

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  - **An innovation** is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).
- The main change compared to previous edition is to focus on **two main types** :
  - **A product innovation** is a new or improved good or service that differs significantly from the firm's previous goods or services and that has been introduced on the market.
  - **A business process innovation** is a new or improved business process for one or more business functions.
    - Business process innovations concern **six different functions** of a firm : production of goods and services, distribution and support functions such as logistics, Marketing and sales, Information and communication systems, administrative and management, product and business process development.
    - These functions match with the third edition's categories of process, marketing and organisational innovations.

1.1. What is innovation ?

- The third edition of the **Oslo Manual** (2005) identified **four types of innovation** :
  - **Product innovation** : the introduction of a good or service that is **new or significantly improved** with respect to its characteristics or intended uses. This includes significant improvements in *technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics*.
  - **Process innovation** : the implementation of a new or significantly improved **production or delivery method**. This includes significant changes in *techniques, equipment and/or software*.
  - **Marketing innovation** : the implementation of a new marketing method involving significant changes in product *design or packaging, product placement, product promotion or pricing.*
  - **Organisational innovation** : the implementation of **a new organisational method** in the firm's *business practices, workplace organisation or external relations*.

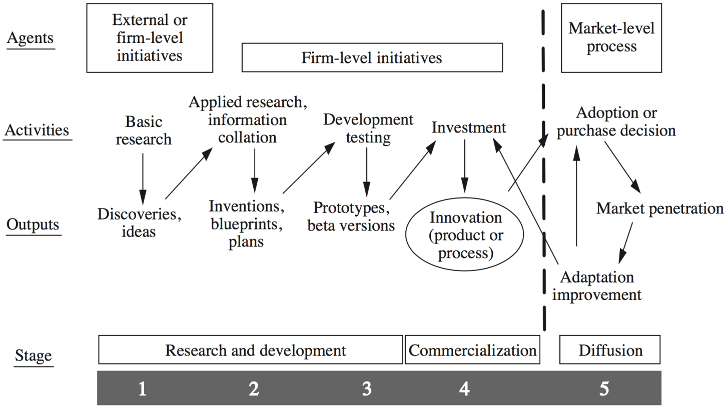
1.2. The stages of the innovation process

- Innovation is associated with **uncertainty** over the outcome of innovation activities.
  - It is not known beforehand what the result of the innovation activities will be
  - Uncertainty regarding the success of the development or commercialization, or the **time and ressources** needed, how successful innovations will be
- Innovation involves **investment** - including acquisition of fixed and intangible assets as well as salaries, purchase of material or services.
- Innovation is subject to **positive externalities** under the form of **knowledge/R&D spillovers** - firms can benefit from knowledge spillovers - imitation costs can be substantially lower than development costs.
- Innovation involves the **utilisation of new knowledge** or **a new use or combination of existing knowledge** generated by the firm (i.e. through intramural R&D) or acquired externally (e.g. purchase of new technology).

1.2. The stages of the innovation process

- Innovation aims at **improving a firm's performance** by gaining or maintaining a **competitive advantage** by
  - **shifting the demand curve** of the firm's products (e.g. increasing product quality, offering new products or opening up new markets or groups of customers) or
  - **shifting the firm's cost curve** (e.g. reducing unit costs of production, purchasing, distribution or transaction), or by
  - improving the firm's **ability to innovate** (e.g. increasing the ability to develop new products or processes or to gain and create new knowledge)

1.2. The stages of the innovation process



Ref : Innovation, Intellectual Property, and Economic Growth, (2010), Christine Greenhalgh , Mark Rogers

2. Mesuring innovation

2.1. Innovation indicators and surveys

- **How to measure innovation ?**

  OECD Proposed Guidelines for Collecting and Interpreting Technological Innovation Data - **Oslo Manual**, fourth edition (OECD/EU/Eurostat 2018)
  - **Innovation inputs**
  - **Innovation outputs**
- **Innovation surveys** (formalized and standardized by the Oslo Manual, OECD, 1992, first edition)
  - **Subject approach** : focus on the innovative behaviour and activities of the firm (= strategies, incentives and barriers to innovation)
  - **Community Innovation Surveys** in Europe (CIS 1, 1990-1992, run at a 2 year intervals and 3-year time-span, CIS 2016)
  - `http://ec.europa.eu/eurostat/web/microdata/community-innovation-survey`
    - Enquête innovation de l'INSEE `https://www.insee.fr/fr/metadonnees/source/serie/s1001`

2.2. Innovation **inputs** : R&D activities

- **R&D is the main measure of innovation inputs.**
  - Proposed Standard Practice for Surveys of Research and Experimental Development - **Frascati Manual**, seventh edition (OECD, 2015) `https://www.oecd.org/sti/inno/frascati-manual.htm`
- R&D - **Research and experimental development** refers to
  - « creative work undertaken on a systematic basis in order to increase the stock of knowledge and the use of this stock of knowledge to devise new applications » (OECD, 2002, p.30)
- R&D activity must possess an **uncertain** element in order to distinguish it from related activities, such as marketing-related activities
  - Pb : auto-evaluation of uncertainty is difficult and its measurement remains a challenge

2.2. Innovation **inputs** : R&D activities

- **Basic/fundamental, applied research or experimental development** activities to acquire new knowledge and direct research towards specific inventions or modifying existing techniques
  - The delineation by firms between these activities is unstable (Czarnitzki and Thorwarth, 2012)
- **Internal vs External R&D** through research contracts or university **collaborations**
- **Input indicators**
  - Total expenditures on innovation [as a % of total turnover]
  - Type of expenditures (machinery acquisition, external knowledge, R&D etc. [as a % of total expenditure on innovation]
  - Share of firms that performed R&D
  - Share of firms that performed R&D on a continuous basis

2.3. Innovation inputs : **non-R&D activities**

- **Non-R&D activities** involve :
  - Identifying **new concepts** for products, processes, marketing methods or organisational changes
  - **Investing in intangible capital** : technical information, paying fees or royalties for patented inventions (which usually require absorptive capacities to adapt and modify to own needs) or know-how and skills through engineering, design
    - **Human skills** can be developed (through internal training) or purchased (by hiring) ; learning by doing.
  - **Investing** in equipment, software or intermediate inputs that embody the innovative work of others

2.4. Innovation **output** indicators

- An **innovation-active firm** is one that has had innovation activities during the period under review, including those with ongoing and abandoned activities.
- **Degree of novelty**
  - **New to the firm** : minimum entry level for an innovation - the innovation may already have been implemented by other firms ; **indicator of imitation**
  - **New to the market** : whether the firm is the first to introduce the innovation in the market or the industry - the market is defined as the firm and its competitors
  - **New to the world** : whether the firm is the first to introduce the innovation worldwide - new for all markets and industries, domestic and international.

2.4. Innovation **output** indicators

- **Impact on turnover**
  - Share of turnover from introduced innovations that are new to the firms, new to the market or new to the world during the observation period
  - Share of turnover from products that were only marginally modified during the observation period
  - Share of turnover that is affected by process innovations or affected by marketing innovations
- **Impact on costs and employment**
  - Whether the process innovation has led to an increase, decrease or no change in costs and interval estimate of the percentage change in costs [5%, 5% to 25%, over 25%]
- **Impact on productivity**
  - Whether process innovations or organisations innovations have improved efficiency (Brynjolfsson and Hitt, 2000, for ICT investments on productivity)
- **Impact on intellectual property**
  - EPO, USPTO patents, Triadic patent families
  - New trademarks, new designs

2.5. Factors hampering innovation activities

Table 7.2. **Factors hampering innovation activities**

Relevant for:	Product innovations	Process innovations	Organisational innovations	Marketing innovations
Cost factors:				
Excessive perceived risks	*	*	*	*
Cost too high	*	*	*	*
Lack of funds within the enterprise	*	*	*	*
Lack of finance from sources outside the enterprise:				
Venture capital	*	*	*	*
Public sources of funding	*	*	*	*
Knowledge factors:				
Innovation potential (R&D, design, etc.) insufficient	*	*		*
Lack of qualified personnel:				
Within the enterprise	*	*		*
In the labour market	*	*		*
Lack of information on technology	*	*		
Lack of information on markets	*			*
Deficiencies in the availability of external services	*	*	*	*
Difficulty in finding co-operation partners for:				
Product or process development	*	*		
Marketing partnerships				*
Organisational rigidities within the enterprise:				
Attitude of personnel towards change	*	*	*	*
Attitude of managers towards change	*	*	*	*
Managerial structure of enterprise	*	*	*	*
Inability to devote staff to innovation activity due to production requirements	*	*		

2.5. Factors hampering innovation activities

Market factors:				
Uncertain demand for innovative goods or services	*			*
Potential market dominated by established enterprises	*			*
Institutional factors:				
Lack of infrastructure	*	*		*
Weakness of property rights	*			*
Legislation, regulations, standards, taxation	*	*		*
Other reasons for not innovating:				
No need to innovate due to earlier innovations	*	*	*	*
No need because of lack of demand for innovations	*			*

Conclusion : CIS Innovation survey : results

- **Access data**
  - Firm data : Comité du Secret Statistique
  - Aggregated data
    Eurostat Database

  http://ec.europa.eu/eurostat/web/science-technology-innovation/data/database
- **Intellectual property**
  - EPO, USPTO patents, Triadic patent families
  - New trademarks, new designs
- **Results**

  http://ec.europa.eu/eurostat/statistics-explained/index.php/Innovation_statistics

3. Measuring the returns to innovation

3.1. Introduction

1. **Do investment in R&D and innovation assets yield private returns ?**
   - **Firms** are interested in **positive private returns** to R&D investment

The aim of R&D expenditures is to increase the **stock of knowledge**

- R&D can increase **productivity** by increasing the quality or reducing the average **production cost** of existing goods or by **widening the spectrum** of final goods or intermediate inputs available.
- Consequences :
  - profit increases
  - price reductions,
  - factor reallocations
  - firm entry and exit

3.1. Introduction

2. **Does R&D carried out in one firm/sector/country produce positive social returns in other firms/sectors/countries ?**
   - **Policy markers** are interested in social or economy-wide returns to R&D investment
   - **Rent or pecuniary spillovers** occur when new or improved intermediate goods or investment goods are sold to other firms at prices lower than the full value of the progress incorporated
   - **Non pecuniary or knowledge spillovers** come from the knowledge created by R&D as it disseminates and is used by other firms.

Caution : « return » to R&D is the outcome of a complex interaction between firm strategy, competitor strategy, and a stochastic macroeconomic environment.

3.1. Introduction

- Coming next ...
  3.2. Measuring private returns through productivity
  3.3. Measuring private returns through firm value
  3.4. Measuring social returns through knowledge and R&D spillovers

3.2. Measuring private returns through productivity

3.2. Measuring private returns through productivity

- Measuring the returns to R&D relies on the **production function** framework
  - Pioneering analytic survey by Griliches (1979) in the Bell Journal of Economics
  - The output of a firm, a sector, or an economy is related to its **stock of knowledge** or knowledge capital and the **stock of external R&D capital**, along with other inputs.
- Raise two major measurement difficulties :
  1. The measurement of output when R&D is devoted to quality improvement and non-market goods
  2. The measurement of inputs, specifically the stock of R&D capital

3.2. Measuring private returns through productivity

- The **Cobb-Douglas** production function **augmented with knowledge capital terms**

$$Y_{it} = A_{it} L_{it}^{\alpha} K_{it}^{\beta} \mathbf{R}_{\mathbf{it}}^{\gamma} \mathbf{R}_{\mathbf{it,E}}^{\phi} e_{it}^{u}$$

  - Y is a measure of production,
  - L is labor input, K is tangible capital
  - R_{it} is own knowledge (intangible) capital
  - $R_{it,E}$ is external knowledge capital
  - u is a disturbance.
  - the coefficient γ measures the elasticity of output with respect to own R&D capital and
  - ϕ the elasticity to external R&D capital.
- What is the rate of return of R&D ?
  - It measures the returns of a marginal increase of R&D, that is, the marginal impact of sales or value added

3.2. Measuring private returns through productivity

- Using logs, the equation becomes linear and easily estimated and

$$
\begin{aligned}
y_{it} &= a_{it} + \alpha l_{it} + \beta k_{it} + \gamma r_{it} + \phi r_{it}^{e} + u_{it} \\
&= \eta_i + \lambda_t + \alpha l_{it} + \beta k_{it} + \gamma r_{it} + \phi r_{it}^{e} + u_{it}
\end{aligned}
$$

- Log of **technical progress (A)** is written as the sum of a sector or firm-specific effect η_i and a time effect λ_t
- γ measures the **elasticity of output with respect to R&D capital** or stock of capital

$$\gamma = \frac{\partial Y}{\partial R}\frac{R}{Y} = \rho_R \frac{R}{Y}$$

  - $\rho_R = \frac{\partial Y}{\partial R}$ is the **rate of return or marginal productivity of R&D capital**
  - ρ_R the gross private rate of return and $\rho^N = \rho_R - \delta$ is the net rate of return with δ the depreciation rate of R&D capital

3.2. Measuring private returns through productivity

- The growth of **Total factor productivity** is the share of growth in output not explained by growth in traditionally measured inputs of labour and capital
- TFP growth can be expressed as a function of **R&D intensity** ($\frac{R\&D}{Y}$) provided that δ is zero or close to it

$$\begin{aligned}
\Delta y_{it} &= \lambda_t + \alpha \Delta l_{it} + \beta \Delta k_{it} + \gamma \Delta r_{it} + \phi \Delta r^e_{it} + u_{it} \\
\Delta tfp_{it} &= \gamma \Delta r_{it} + \phi \Delta r^e_{it} + u_{it} \\
&= \gamma \Delta r_{it} + \phi \Delta r^e_{it} + u_{it} \\
&= \rho \frac{R\&D - \delta R_{i,t-1}}{Y_{it}} + \phi \Delta r^e_{it} + u_{it} \\
&= \rho \frac{R\&D}{Y} + \phi \Delta r^e_{it} + u_{it}
\end{aligned}$$

given that

$$\gamma \Delta r = \frac{\partial Y}{\partial R} \frac{R}{Y} \frac{\dot{R}}{R} = \rho \frac{\dot{R}}{Y} = \rho \frac{R_{it} - \delta R_{i,r-1}}{Y_{it}} \approx \rho \frac{R\&D}{Y} \qquad \text{with } \dot{R} = \frac{dR}{dt}$$

3.2. Measuring private returns through productivity

There are at least four measurement issues (Grilliches, 1980 ; Hall et al. 2010)

1. Conventional measures of capital and labor also contain elements of R&D, which is **double-counted** because
   - R&D workers are included in the total labor force head count and
   - R&D related investments are included in the overall capital stock

   ⇒ R&D stock leads to an estimate of the **excess gross rate of return** to R&D

2. **Output can be measured by value added (= gross output) or sales**
   - Value-added is the output obtained from the combined use of labor and capital, i.e. gross output less purchased inputs such as materials
   - Usually VA is preferred because of a lack of information of materials and omitting materials in the sales regression yields an upward bias in the R&D elasticity because materials are correlated with R&D

3.2. Measuring private returns through productivity

3. Assumption : R&D creates a **firm-level stock of knowledge** that yields returns in the future ⇒ constructing the stock requires depreciating the past stock

- Pb : **how fast** do R&D expenditures enter or exit the relevant stock of knowledge ?
  - Usually studies use a simple perpetual inventory with a single depreciation rate to construct the knowledge capital produced by R&D

$$K_{it} = (1 - \delta)K_{i,t-1} + R\&D_{it}$$

- What is the starting point ?
  - To compute the starting R&D stock at the first available observation year of R&D spending, it is assumed a constant annual R&D growth rate prior to the observed history, g (8% for example - Hall and Oriani, 2006 ; Hall, Thomas, Torrisi, 2007)

$$K_0 = \frac{1}{\delta + g} R\&D_0$$

- K is the knowledge stock of firm i at time t, and R is real investment at time t and δ is a depreciation rate

3.2. Measuring private returns through productivity

- Pb : the depreciation rate varies across firms and time : it is endogenous to the firm's and competitors' behavior in addition to depending on the progress of public research and science but unknown... thus
- Most researchers use $\delta = 15\%$ as set by Griliches

4. **What are the lag effets ?**
    - It is unlikely that the latest addition to the R&D stock becomes productive immediately, because of the lag from expenditure to innovation, and from innovation to commercialization
    - A number of survey responses from companies suggest time lags between development and new product of 1-2 to 5 years.

3.2. Measuring private returns through productivity

Elasticity to R&D and rate of return to R&D

- Estimations of elasticity and rate of returns based on individual firm or plant data show significant impact of R&D on production
  - Elasticities range between 5 and 30%

$$\gamma = \frac{\partial Y}{\partial R}\frac{R}{Y} = \rho_R(R/Y)$$

  - The rate of returns or marginal productivity of R&D capital ranges between 10 and 80%.

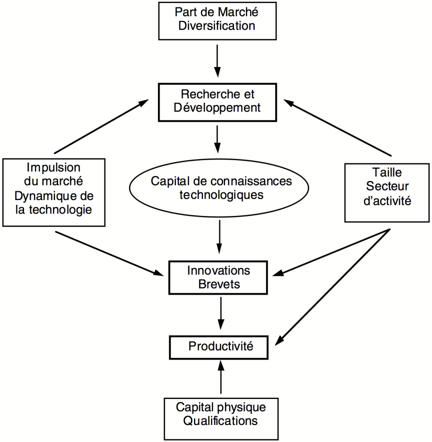
$$\rho_R = \frac{\partial Y}{\partial R}$$

Empirical analysis of the returns to innovation

Crépon B., Duguet E., Mairesse J. (2000), Mesurer le rendement de l'innovation, Economie et statistique, 334, 65-78

Empirical analysis of the returns to innovation

- Aim : measuring returns to innovation
- The model



Empirical analysis of the returns to innovation

- **Data** : 4100 French firms from manufacturing industries
- Innovation indicators : # of patents and % of innovations within sales
- **The model**
  - **Decision to do R&D** (R = anticipated gain of research - non observable) - Anticipated gains of R&D investments (selection)
  - **Decision of the amount of capital invested in research activities** (K)
    Diversification is measured by the number of industrial activities
    Market pull : role of clients, competition, size and growth of demand pulling innovation
    Technology push : rate of technological inventions

$$\ln R = F(\ln \text{Employment}, \ln \text{Market share}, \ln \text{Diversification}, \text{Market Pull}, \text{Technology push})$$

$$\ln K = F(\ln \text{Employment}, \ln \text{Market share}, \ln \text{Diversification}, \text{Market Pull}, \text{Technology push})$$

Empirical analysis of the returns to innovation

- **The model**
  - **Two indicators of innovation**

  1- I : share of sales due to less than five year old products or share fo renewed products

$$\ln I = F(\ln K, \ln \text{Employment}, \ln \text{Market share}, \text{Market Pull}, \text{Technology push})$$

  2- The number of patents

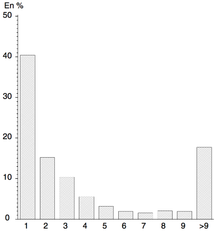
  - **Productivity equation** : $P = VA/EMP$

$$\ln P = F(\ln I, \ln \text{Employment}, \ln \text{Capital}, \text{Ingeniers}, \text{Adm. staff})$$

Empirical analysis of the returns to innovation

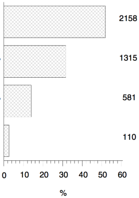
Graphiques I et 2. Brevets et ventes

Graphique I
Répartition du nombre de brevets européens déposés (1986-1990)



Lecture : 40 % des entreprises qui brevettent ont déposé un seul brevet.
Champ : entreprises de 20 employés ou plus dans l'industrie manufacturière. Ce graphique ne concerne que les 16,1 % entreprises qui brevettent.
Source : European Patent Office *(base Insee-OST).*

Graphique II
Part des ventes en produits de moins de 5 ans (1990)



	Effectif		Pourcentage	
	Simple	Cumulé	Simple	Cumulé
0-10%	2158	2158	51.83	51.83
10-30%	1315	3473	31.58	83.41
30-70%	581	4054	13.95	97.36
>70%	110	4164	2.64	100.00

Lecture : 2,64 % des entreprises innovantes ont réalisé plus de 70 % de leur chiffre d'affaires de 1990 en produits nouveaux (elles sont 110).
Champ : entreprises de 20 employés et plus dans l'industrie manufacturière.
Source : enquête Innovation du *Sessi (1991).*

Tableau 1
Estimation des modèles

Variables explicatives	Recherche-Développement		Modèle avec brevets		Modèle avec pourcentage d'innovation	
	Probit (décision)	Tobit (montant)	Brevets par employé	Productivité	Innovation (%)	Productivité
Capital de R-D par employé (K en logarithme, endogène)	x	x	1,078* (0,166)	x	0,304* (0,064)	x
Nombre de brevets par employé (BREV en logarithme, endogène)	x x	x x	x x	0,089* (0,015)	x	x
Pourcentage d'innovations (INO en logarithme, endogène)	x	x	x	x	x	0,065* (0,015)
Part de marché (PM, en logarithme)	0,221* (0,031)	0,356* (0,053)	x	x	x	x
Diversification (DIV, en logarithme)	0,302* (0,103)	0,333* (0,142)	x	x	x	x
Emploi (EMP, en logarithme)	0,387* (0,040)	- 0,043 (0,066)	- 0,066 (0,073)	- 0,014 0,007	- 0,002 (0,028)	(0,007) (0,004)
Intensité capitalistique (CAP-EMP, en logarithme)	x	x	x	0,194* (0,007)	x	0,198* (0,007)
Ingénieurs/Emploi (PI, en niveau)	x	x	x	1,614* (0,123)	x	1,649* (0,123)
Cadres/Emploi (PA, en niveau)	x	x	x	1,744* (0,143)	x	1,765* (0,142)
Impulsion de la demande (DP, indicatrices) :						
– faible	0,261 (0,192)	0,377 (0,308)	- 0,071 (0,332)	x	- 0,040 (0,150)	x
– moyenne	0,191 (0,170)	0,342 (0,277)	- 0,068 (0,315)	x	0,164 (0,137)	x
– forte	0,343* (0,164)	0,412 (0,272)	0,074 (0,304)	x	0,399* (0,133)	x
Dynamique de la technologie (TP, indicatrices) :						
– faible	0,173 (0,120)	0,173 (0,207)	- 0,237 (0,254)	x	0,229* (0,089)	x
– moyenne	0,322* (0,113)	0,604* (0,198)	- 0,540* (0,255)	x	0,268* (0,092)	x
– forte	0,444* (0,117)	0,907* (0,202)	- 0,483 (0,277)	x	0,333* (0,105)	x
* Significatif au seuil de 5 %.						

Lecture : l'estimation est réalisée par les moindres carrés asymptotiques à partir des estimateurs du maximum de vraisemblance et du pseudo-maximum de vraisemblance de la forme réduite.
Équation de recherche : la partie « probit » de l'équation concerne la décision de faire de la recherche, la partie « tobit » concerne le montant investi en recherche sachant la décision.
Équation de brevets : on explique le logarithme de l'espérance du nombre de brevets par employé par le logarithme de la recherche. Les brevets entrent alors dans la fonction de production.
Équation d'innovation : on explique le logarithme du pourcentage de produits innovants par le logarithme des dépenses de recherche, et ce pourcentage (en logarithme) entre lui-même dans la fonction de production.
Source : calculs des auteurs.

Empirical analysis of the returns to innovation

Results

- Technology push (when it is easy to develop new products or processes) has a strong impact on investment R&D
- The role of consumer demand and competition has an impact on innovation but not on patenting
- The # of patents per employee and the innovation have a positive impact on firm productivity.
- Large firms with large market shares are more diversified and have higher incentives to do research than smaller ones, and invest higher amounts per employees.

3.3. Measuring private returns through firm value

3.3. Measuring private returns through firm value

- R&D conducted by private firms is **capitalized** as a firm's knowledge stock which contributes to the firm's future net cash flows
- **What is the market value of knowledge assets ?**
  - In financial markets, investors estimate a company's value according to the prospective returns that they expect from its assets, embodied in its stock price
  - The **market value** can therefore be viewed as a **forward-looking measure of firm performance** (Hall, 2000).
- The market value approach assumes that the price of a company, determined in the financial market, is a function of the assets (tangible and intangible) of the company (Hall et al. 2005 ; Sander and Block, 2011, Research Policy)

3.3. Measuring private returns through firm value

- Following the initial work of Griliches (1981), the typical linear market value model assumes that firm's assets enter the market value equation as

$$V_{it}(A_{it}, K_{it}) = q_{it}(A_{it}, \gamma K_{it})^{\sigma}$$

  - V_{it} **is the market value of company** i at time t, A **is physical asset**, and K **is knowledge assets** (such as R&D and patents) ;
  - σ measures *returns to scale* and is unity if the value function is homogeneous of degree one, indicating constant returns to scale ;
  - γ mesures *the marginal value of knowledge assets* and reflects the contribution to the company's value when one additional unit is spent on knowledge assets.

3.3. Measuring private returns through firm value

- Taking logarithms

$$logV_{it} = logq_t + \sigma logA_{it} + \sigma log\left(1 + \gamma\left(\frac{K_{it}}{A_{it}}\right)\right)$$

- If $\sigma = 1$, the value function exhibits constant returns to scale and $logA$ can be moved to the left-hand side of the equation
- The model is thus estimated with the conventional **Tobin's q** as the dependent variable

$$log\ Q_{it} = log\left(\frac{V_{it}}{A_{it}}\right) = log\ q_t + log\left(1 + \gamma\frac{K_{it}}{A_{it}}\right) + \epsilon_{it}$$

Q_{it} is the Tobin's q, and the intercept can be interpreted as an estimate of the logarithmic average of Tobin's q for each year.

Empirical analysis of the market value of R&D stock, patents and trademarks

Sandner P. and Block J. (2011), The market value of R&D, patents, and trademarks, Research Policy, 40 (2011), 969-985

Empirical analysis of the firm market value

- The **knowledge-creation process** is seen as a **continuum going from R&D to patents to citations** :
  - **R&D** reveals the commitment of a firm's resources to innovation
  - **Patents** reveal the success in generating codifiable new knowledge that the firm can in principle appropriate
  - **Citations** indicate the extent to which those innovations turn out to be « important » and hence presumably more valuable to the firm.
  - **Trademark** rights are an essential instrument for companies to protect their acquired assets against impairment.
    - Trademarks serve to protect brands (= name, sign, symbol, design...) and marketing assets (= advertising, successful launch of new products and maintenance of high level service and product quality).

Empirical analysis of the firm market value

- The estimated model :

$$\begin{aligned} log\ Q_{it} &= log\left(\frac{V_{it}}{A_{it}}\right) \\ &= log\ q_t + log\left(1 + \gamma_1 \frac{R\&D_{it}}{A_{it}} + \gamma_2 \frac{PAT_{it}}{R\&D_{it}} + \gamma_3 \frac{CITES_{it}}{PAT_{it}} + \gamma_3 \frac{TM_{it}}{MA_{it}}\right) + \epsilon_{it} \end{aligned}$$

- $\frac{R\&D_{it}}{A_{it}}$, the share of intangible (R&D stock) versus physical capital stock tangible capital
- $\frac{PAT_{it}}{R\&D_{it}}$, the number of patents per dollar of R&D ;
- $\frac{CITES_{it}}{PAT_{it}}$ the stream of citations received over time is correlated with both the private and social value of patented innovations ;
- $\frac{TM_{it}}{MA_{it}}$ trademarks over marketing assets = the intensity to which a firm protects its marketing efforts by means of trademarks.

Empirical analysis of the firm market value

- Data
  - Accounting and financial market data form Compustat from 1990 to 2006
    - R&D expenditures, market capitalization at the end of each year
  - Trademark data from CTM register provided by the OHIM
  - Patent data come from PATSTAT
    - Patents and trademarks were consolidated on the corporate level from 1996 and 2002
- 1232 publicly traded companies with revenues of at least 400 millions Euros

Empirical analysis of the firm market value

- Variables
  - Log Tobin's q - ratio of the market value (V) to the book value of assets (A) reported by the balance sheet - the market value is the sum of the market capitalization (= stock price times number of shares) and the market value of its debt.
  - Knowledge asset : R&D stock with a depreciation rate of $\delta = 15\%$

    $$RD_t^{stock} = (1-\delta)RD_{t-1}^{stock} + RD_t^{flow}$$

    Patent Stock

    $$PAT_t^{stock} = (1-\delta)PAT_{t-1}^{stock} + PAT_t^{flow}$$

    etc.
- Estimation method : Non-Linear Least Squares (NLLS) (Hall et al. 2005)
  - Coefficients of linear models are not easy to interpret, thus compute elasticities for each of the key regressors with respect to Tobin's q.

Table 5
Market value regressions of knowledge assets and trademark stocks.

Variables(Dependent variable: Tobin's q)	Model M0	Model M1	Model M2	Model M3	Model M4	Model M5
Log (assets)	−0.0107	−0.0155*	−0.0126	−0.0226**	−0.0121	−0.0022
	(0.0095)	(0.0094)	(0.0010)	(0.0096)	(0.0101)	(0.0103)
R&D stock/assets		0.6333***	0.6342***	0.5292***		0.3188*
		(0.1848)	(0.1847)	(0.1893)		(0.1898)
Patent stock/R&D stock			0.0006	−0.0012		−0.0026
			(0.0032)	(0.0034)		(0.0044)
Citation stock/patent stock				0.1553***		0.1485***
				(0.0286)		(0.0284)
Trademark stock/marketing assets					13.5040***	11.816***
					(2.5929)	(2.6212)
Control variables						
No R&D		−0.0055	−0.0200	−0.0221		−0.0366
		(0.0355)	(0.0351)	(0.0355)		(0.0346)
No patents			0.0881	0.1337***		0.1307***
			(0.0432)	(0.0437)		(0.0429)
Year dummies (6 cat.)	Yes	Yes	Yes	Yes	Yes	Yes
Country dummies (10 cat.)	Yes	Yes	Yes	Yes	Yes	Yes
Industry dummies (14 cat.)	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.4304***	0.3305***	0.3015***	0.3376***	0.1331	0.1282
	(0.0907)	(0.0979)	(0.0988)	(0.0982)	(0.0907)	(0.1084)
Diagnostics						
R^2	0.291	0.300	0.302	0.312	0.307	0.320
Log likelihood	−5318.78	−5275.06	−5265.23	−5214.70	−5241.89	−5164.93
Δ(Log likelihood)		87.43***	9.83***	50.53***	76.89***	153.85***
Compared model		M0	M1	M2	M0	M0
Elasticities $\partial\log(V/A)/\partial\log X$						
R&D stock/assets		0.0594***	0.0595***	0.0469***		0.0275***
		(0.0163)	(0.0163)	(0.0160)		(0.0156)
Patent stock/R&D stock			0.0001	0.0002		−0.0005
			(0.0006)	(0.0006)		(0.0008)
Citation stock/patent stock				0.0637***		0.0591***
				(0.0110)		(0.0106)
Trademark stock/marketing assets					0.0628***	0.0506***
					(0.0113)	(0.0108)

Notes: $N = 6757$ observations from $N = 1216$ companies. Estimation method: NLLS. Clustered standard errors in parentheses. Reference group for industry: 'electronics and components'. Reference country: US. Reference year: 2002.

* Significance level $0.10 > p \geq 0.05$.
** Significance level $0.05 > p \geq 0.01$.
*** Significance level $p \leq 0.01$.

Conclusions

- Results reveal that financial markets value the quality of patents
  - Cites per patent are more important than patent yield per R&D (confirms previous results by Hall, Jaffe and Trajtenberg in the Rand Journal of Economics, 2005)
    - Increase of one cite per patent $\Rightarrow$ increase of 3% market value
    - Below the median, cites per patent has no effect
    - $=$ Investors value primarily those patents that receive a lot of citations (Hall et al., 2005).
    - High self-citation share is valuable. It is worth about twice as much if the firm is small or medium sized, neutral if firm is large (appropriability)
- Results reveal that financial markets value the registration of trademarks
  - Trademarks are viewed as an effective tool to at least partially appropriate the value of marketing investments.

3.4. Measuring the Social returns - Externalities

3.4. Measuring the Social returns - Externalities

- The R&D executed in one firm can affect productivity performance of other firms operating in the same industry or in other industries, locally or abroad
- Two kinds of spillovers (Griliches, 1992)
  - **Rent spillovers** occurs when a firm or consumer purchases R&D-incorporated goods or services at prices that do not reflect their user value because of imperfect price discrimination, imperfect appropriability and imitation
    - The more competitive markets, the less ability firms have to appropriate the benefits of their R&D and the more pecuniary spillovers will take place.
  - **Knowledge spillovers** occurs when an R&D project produces knowledge that can be useful to another firm in doing its own research.
    - Knowledge is a non rival and only partially excludable good because of weak and incomplete patent protection, inability to keep innovations secret, reverse engineering and imitation.
    - Knowledge spillovers are higher when knowledge is codified and firms have high absorptive capacities.

3.4. Measuring the Social returns - Externalities

- Knowledge spillovers is very relevant for growth and development because it drives knowledge creation and diffusion
  - Distinguish knowledge spillovers from **knowlege transfers** which refer to trade in technology = when agents sell technology with a price attached to the transaction
  - Knowledge spillovers are **nonpecuniary spillovers** = refers to **unintended** knowledge transfers in which **no payment is involved**.
- Spillovers can come from R&D done by
  - other firms in the sector
  - firms in other industries
  - public research laboratories and universities in the country/region and
  - firms, laboratories and governments in other countries

3.4. Measuring the Social returns - Externalities

How large are the social rates of return on R&D ?

- Most studies estimate the aggregate or social returns to R&D through an econometric approach estimating **the relationship between productivity and R&D**.
  - Inclusion of an aggregated economy-wide R&D stock in the usual TFP equation
  - The majority of studies go further and specify **the channel** through which the spillovers come and estimate a return to this external R&D.
- The R&D spillover variable is measured as a weighted sum of the R&D stock from sources outside the firm
  - a_{ij} weights are proportional to some flows or **proximity measures** between firm, industry or country i, the receiver of R&D spillover, and firm, industry or country j, the source of R&D spillover.

$$S_{it} = \sum_{j \neq i} a_{ji} R_{jt}$$

3.4. Measuring the Social returns - Externalities

How large are the social rates of return on R&D ?

- Flows such as investment in capital goods, hiring of R&D personnel, attendance at workshops, seminars, trade fairs, collaborations, adoption of new technologies, flows of patents from industry of origin to industry of use, and patent citations.
  - The intuition : the more j trades with i, invest in i, collaborate with i, cited by i , the more it is likely to diffuse its knowledge to i.
  - Pure knowledge spillovers can also be measured independently of any transaction simply on the basis of proximities in various types of space.
    - These proximities can be uncentered correlation coefficients between positions in patent classes (Jaffe, 1986), fields of research (Adam and Jaffe, 1996), etc.

3.4. Measuring the Social returns - Externalities

- **Rent and knowledge spillovers** are expected to be **positive**

but there can be **negative spillovers** associated with R&D

  - **Market stealing effect** for spillovers in industries at the firm level when new products render old products obsolete (creative destruction) (Bloom et al. 2007)
  - Market stealing effects at the social level when R&D is used as a mere strategy to preempt competition or when **patent races** lead to duplicated R&D (Jones and Williams, 1988) = congestion externalities

- Spillovers have been estimated at various level of aggregation - countries, sectors, firms, projects, intra and intersectoral, domestic and international
  - In general, spillovers have been found to be quite large,

    but rather imprecisely estimated, but when the estimates have no time trends or time effects, external R&D coefficients may be biased upward due to confounding influences.

3.4. Measuring the Social returns - Externalities

- The social rate of return is obtained by adding the private rate of return (the benefit to the firm that performs the R&D) to the sum of the returns on outside R&D for all recipients of spillovers from that firm :

$$\frac{\partial Y_{it}}{\partial R_{it}} + \sum_{i \neq j} \alpha_{ij} \frac{\partial Y_{jt}}{\partial S_{jt}}$$

  - The magnitude of the social rate of return depends of course on the number of spillover receivers.
    - Social rate of US R&D will be greater if all countries of the world are included : only the G-7 countries are involved (Coe and Helpman, 1995) vs Coe et al. (1997) with spillovers from 22 developed countries.

Empirical analysis of spillovers

Jaffe A.B., Technological opportunity and spillovers of R&D : evidence from firm's Patents, Profits and Market Value, The Americal Economic Review, 76(5), 984-1001

Empirical analysis of spillovers

- Estimates the impact of R&D spillovers on firm productivity
  - Role of R&D of technological neighbors
  - Results :
    - R&D Productivity is increased by the R&D of technological neighbors (= Positive knowledge externalities)
    - But neighbors' R&D lowers the profits and market value of low R&D intensity firms = market stealing effect

Empirical analysis of spillovers

- Since knowledge is a public good, the research efforts made by other firms is considered as an input for the knowledge production function (Jaffe, 1986)

$$S_i = \sum_{j \neq i} T_{ij} R_j \qquad \text{with } T_{ij} = \frac{\sum f_{ik} f_{jk}}{\sqrt{\sum_k f_{ik}^2 \sum_k f_{jk}^2}}$$

- T_{ij} is **Technological proximity** is computed as an uncentered correlation of two vectors f_{ik} and f_{jk} representing each firm i and j technological position in terms of k classes (for example 4 digit IPC classes.

Empirical analysis of spillovers

- Data : 432 firms from the NBER R&D panel - two cross section centered on 1973 and 1979

TABLE 2—STATISTICS FOR REGRESSION VARIABLES

	Levels (864 Observations)[a]			Log of Levels (864 Observations)		Difference of Logs (1979/1973) (432 Observations)	
	Mean	Median	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Patents	35.5	9.3	120.4	2.30	3.29	−.304	.743
Gross Profits	207.9	32.7	868	4.07	4.62	.243	.475
Tobin's q	1.02	.84	1.80	−.0323	.882	−.142	.512
Annual $R\&D$	25.7	3.41	108	1.80	2.98	.177	.562
$R\&D$ Stock	121	12.5	98.2	3.51	3.09	.239	.611
Capital Stock	968	153	3562	5.64	6.05	.290	.332
Annual Spillover Pool	2622	2438	2980	7.78	7.80	.152	.344
Spillover Pool Stock	10042	9986	2004	9.45	7.75	.208	.329
Market Share	5.44	3.24	6.23	.848	1.12	–	–
Four-Firm Concentration	38.3	37.1	43.2	3.57	3.62	−.049	.152

Note: All nominal variables are millions of 1972 dollars. Market share and concentration are percentages.
[a] Except for market share, which has only 432.

Empirical analysis of spillovers

TABLE 3—POOLED *OLS* ESTIMATES FOR 1973 AND 1979
(864 Observations)

Coefficient	Equation for log of: Patents	Profits	Tobin's q
log($R\&D$)	.735	.201	
	(.152)	(.051)	
$R\&D$/Capital			2.95
			(1.52)
log($R\&D$) × log(Pool)	.168	.027	
	(.031)	(.020)	
($R\&D$/Capital) × log(Pool)			.526
			(.192)
log(Pool)	.628	−.078	−.077
	(.108)	(.043)	(.052)
log(Capital)		.564	
		(.024)	
log(72 Share) in 1973		.385	.453
		(.021)	(.043)
log(72 Share) in 1979		.272	.315
		(.021)	(.033)
log(Four-Firm Concentration Ratio)		−.159	−.438
		(.040)	(.052)
F-Statistics for Technological Cluster Dummies (20 *D.F.*):			
1973	4.2	5.8	5.6
1979	3.9	5.7	5.5
R^2	.94	.44	.77
$\hat{\sigma}$	.806	3.46	.509

Note: Each equation includes 21 technological cluster dummies for each year.

What are the channels of transmission of R&D spillovers

see chapter 3. Geography and knowledge flows

- Study the way in which knowledge is transmitted from firm to firm and from public research to firm.
  - **Individual workers/researchers/inventors** as carriers of tacit knowledge
    - **Researcher mobility** across firms or countries brings with it the transmission of knowledge
    - Researchers do not move but their **personal connections** help knowledge to diffuse across firms and borders (Almeida and Kogut (1999) , Kerr, 2008 ; Agrawal, Cockburn and McHale 2006), Gone but not forgotten, knowledge flows, labor mobility and enduring social relationships.)
  - **Impact of academic research**
    - Adams (1990) measures for each industry a stock of academic science by the count of past and present academic publications by science field - Academic scientific knowledge in the own industry accounts for 50 % of TFP growth and academic knowledge in other industries account for 25% of TFP growth
    - Jaffe (1989) : university research in a state produces spillovers in terms of corporate patents granted in that state : the direct elasticity is approximately 0.1 and rises to 0.6 when the inducement effect of corporate R&D is taken into account.

  - (Adams, 1990 ; Lissoni, 2010, Academic inventors as brokers, Research Policy)

3. Patent statistics

3. Patent statistics

- Innovation is considered to be the engine of economic growth but measuring innovation is not easy
  - Innovation surveys help identify major innovations and count them can be informative, however it is difficult to provide an overall picture of innovation in a continuous manner
  - R&D expenditures is often used as a proxy for innovation or technological progress but expenditure is an input rather than an output for R&D activities which is not innovation
- Patent information is increasingly used to analyze innovation and the innovation process
  - Patents have been the only source of rich information on new technology
  - it is used by governments to measure technological progress and innovation
  - It is used by firms to monitor the technological developments and patenting activities of rivals

3. Patent statistics

- Patent statistics are difficult and resource consuming to use for statistical analysis because of their size, and not statistics-friendly way of storing them $\Rightarrow$ availability of patent databases makes it easier to conduct sophisticated statistical analysis.
    - The seminal National Bureau of Economics Research (NBER),
    - OECD REGPAT
    - EPO PATSTAT `https://www.epo.org/searching-for-patents/business/patstat.html#tab-1`
    - USPTO PatentsView datasets : `https://patentsview.org`
- Research papers using patent statistics increase at a faster rate than patent themselves

3.1. Patent statistics : Introduction

Some caveats are in order

- Not all patents represent innovation, nor all innovations are patented
- The value of patents is highly skewed, as there are a small number of highly valuable patents and a large number of patents with little value.
    - about 10% of the most valuable patents account for more than 80% of the value of all the patents, based on their survey of German patents (Scherer and Harhoff, 2000)
    - According to the JPO survey, more than 60% of patents are neither used internally nor licensed out.
    - Firms often use patents strategically, i.e. use patents to simply block other firms' patents or to deter entry.
- Many inventions are not patented
    - The invention must satisfy some criteria : novelty, nonobviousness and industrial usefulness
    - Firms deliberately choose not to patent their inventions to avoid disclosure - protection through trade secret instead

Patents : rich source of information

- Patents ⇒ Patent stock
- Inventors ⇒ Co-authorship, Inventor networks = ⇒ relationships between inventors ; inventor productivity
- Applicants ⇒ Co-patenting ; Applicant networks ⇒ relationships between applicants
- Inventor location ⇒ geographical location of inventions, cross-region / cross-country collaborations
- Citations ⇒ knowledge sourcing and knowledge flows : who cites whom from where - intra-organisational knowledge flows within multinationals or inter-organizational flows
- Citation ⇒ Technological importance - give rises to subsequent technological developments ⇒ Technological value of patents highly correlated to economic value

Source : Handbook of Innovation economics, Hall and Rosenberg, 2010.

https://worldwide.espacenet.com/advancedSearch?locale=fr_EP

3.2. Information in the patent documents

« Using Patent Data as Science and Technology Indicators - **Patent Manual** » (OECD, GD, 1994 ; 2009)
`http://www.oecd.org/sti/inno/oecdpatentstatisticsmanual.htm`

Patent database developed for academic research (NBER patent database, PATSTAT) use mainly

1. Application, including title, abstract, and technology class
2. Priority and patent family
   - A patent family is « the set of patents (or applications) filed in several countries which are related to each other by one or several common priority filings » (OECD, 2008)
     - Example : OECD triadic patent family use the priority date information of international patent applications to EPO, JPO and USPTO (granted in the US). According to the Paris convention or the PCT rule, the priority date (application date of the original application) can be kept for patent applications for another country (or region) when inventions are equivalent
     - Important for patent count : many patents but only one invention !

3.2. Information in the patent documents

3. Grant : patent application does not mean patent granted. Only the grant give a property right
4. Applicant and assignee
   - Increasing tendency of international co-ownership (or co-application)
5. Inventor
   - Increasing tendency of international co-authorship
   - Inventor address is either business address or home adress and enables to locate the invention made
   - Measure the size of the research team - the average size is 2.7-2.9 and size with five or less inventors account for 90% of patents

   Problem with inventor names - misspellings and disambiguation - is John Smith in Patent A the same as John Smith in Patent B

   Problem with applicants - need consolidated portfolios within corporations (headquarters and subsidiaries)
6. Citation relationship -citations are made mostly by applicants in the US and mostly by examiners in EPO (only 9% inventor citations in 2000)

3.3. Patent statistics and innovation activities

- Innovation can be understood as the process of converting technological or nontechnological inventions into new products, services and processes to generate economic returns.
  - Patents can be an input and an output of this process.
- The role of patents in innovation activities
  - Patents can be an output of the knowledge production function with R&D as an input for innovation
  - Patents (the #) can be used as a proxy of knowledge capital and used as one of the inputs to the production function to explain a firm's performance such as productivity (Griliches, 1990)

3.4. The knowledge production function

Patents as an innovation output

- Patents used as indicators of inventive activities
  - Since patentability requires both novelty (and inventive step) and utility, applied research is most likely to produce patents
    Pb for basic research because of the need of a specific utility
- **The knowledge production function** (Griliches, 1979, Jaffe, 1986)
  - The new knowledge produced by the firm *i* in any period is related to its R&D and spillovers (all variables in logs)

$$k_{it} = \alpha + \beta r_{it} + \gamma s_{it} + \gamma x_{it} + \epsilon_{it}$$

  - Knowledge is not observed but proxied through the number of patents

$$p_{it} = \alpha + \beta r_{it} + \gamma s_{it} + \gamma x_{it} + \epsilon_{it}$$

3.4. The knowledge production function

Patents as an innovation output

- Since knowledge is a public good, the research efforts made by other firms is considered as an input for the knowledge production function $s = log(S)$ (Jaffe, 1986)

$$S_i = \sum_{j \neq i} T_{ij} R_j \qquad \text{with } T_{ij} = \frac{\sum f_{ik} f_{jk}}{\sqrt{\sum_k f_{ik}^2 \sum_k f_{jk}^2}}$$

- T_{ij} is Technological proximity is computed as an uncentered correlation of two vectors f_{ik} and f_{jk} representing each firm i and j technological position in terms of k classes (for example 4 digit IPC classes.

3.5. The valuation of patents

- The literature distinguishes between
  - The social and the private value
  - The monetary and technological value
- The private value distribution of patents is highly skewed
  - Only accounting for the number of patents can be misleading
- The most used patent quality indicators are
  1. Forward citations : citations from subsequent patents
  2. Patent renewal information
  3. Patent family size and scope
- Backward citations : citations to previous patents
  - Self-citation - cumulativity
  - Knowledge spillovers

3.5. The valuation of patents

Forward citations : patent quality indicator

- The number of forward citations reflects **the technological importance** of the patent
- Technological progress is **cumulative**
  - a large number of forward citations means that the patent enabled many other **subsequent inventions**
  - Such patent tends to yield more profit for the inventing firm, since the invention is technologically more important and it may have **wider applications**

    If I can see further than anyone else, it is only because I am standing on the shoulders of giants —*Isaac Newton*
- Forward citation is also an indicator of **the social value** of the patent : the patent has been a source of knowledge spillovers for other patents

3.5. The valuation of patents

Characteristics of forward citations

- **Patent citation takes time - truncation** problem since older patents have the time to receive more citations - solution : use forward citations within the first 5 years
  - More than 50% of citations received in the entire life or a patent occur within the first 5 year for the UPSTO (OECD, 2008)
- **The number of citations varies by the technological field of a patent.**
  - The average citation in biotechnology was 5.3 while that of computer software was 19.9 for the triadic patents of the US origins from 1995 to 1999 One way to control them is to use relative forward citation counts within the same application year and technology field.

3.5. The valuation of patents

Characteristics of forward citations

- **The laws and practices regarding citations are different across countries.**
  - Under the US patent system, an applicant has to cite all relevant patent and nonpatent literature in addition to the citations made by examiners
  - Patent citation data at the EPO and JPO is generated in a process of patent examination
  - The number of citations per patent is substantially larger for the US patents than EPO or Japanese ones

3.5. The valuation of patents

Patent family size, scope and opposition : patent quality indicators (see van Zeebroeck, 2011)

- **Patent family** : The number of countries for which the same invention is patented (patent family size) is also an important indicator of patent quality (see Harhoff et al., 2003a ; Lanjouw et al., 1998).
  - International patenting is much more costly than domestic applications
  - the fact that a patent holder wants to secure patent protection in various countries and regions, implies that she has a higher expectation of return from the patent.
- **The patent family size** is available in a more timely fashion
- **The patent technological scope** (Lerner, 1984) : the number of technological fields covered by the patent - enables use of many sectors thus increase the economic value

3.5. The valuation of patents

Patent family size, scope and opposition : patent quality indicators (see van Zeebroeck, 2011)

- **Opposition** to patent grants and patent litigation information
  - Such actions are not free, and the opposing party must see some economic value greater than the legal cost (Harhoff et al., 2003a ; Lanjouw, 1998).
  - Pb : only a small fraction of patents are opposed or litigated

3.6. The monetary value of patents

Patent renewal information

- The patent holder has to pay periodic fees to maintain his patent rights.
  - The longer the patent right is kept, the greater its economic value
- Patent renewal information enables to estimate patent value (Schankerman and Pakes, 1986)
  - Most patents have little or no value, as such, patent holders cease to renew them
  - The distribution of patent value becomes more skewed toward the latter stage of the patent life.
- Limit : wait until the end of patent life to conduct an analysis – difficult to evaluate the value of young patents and truncation

3.6. The monetary value of patents

Surveys

The monetary value is assessed through expert and firms surveys

- Harhoff D., Narin F., Scherer M. and Vopel K., (1999), Citation frequency and the value of patented inventions, The Review of Economics and Statistics, 81(3), 511-515
    - 964 inventions made in the US and Germany - citations and renewal fees
    - Patents renewed to full-term are significantly more highly cited than patents expiring before term
    - Patents reported to be relatively valuable by the companies holding them are more heavily cited in subsequent patents

Empirical analysis of the value of patents Gambardella A., Harhoff D. and Verspagen B. (2008), The value of European Patents, European Management Review, 5, 69-84

Empirical analysis of the value of patents

- PatVal-EU survey collected data on more than 9000 patents with priority date 1993-1997 granted at the EPO and with inventor EU address.
- Response questionnaire produced by inventors
- The estimated mean-value of the patent distribution is about 3 million euros, while the median is 400 thousand euros

Empirical analysis of the value of patents

Empirical investigation

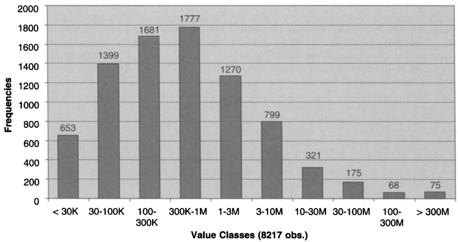


Figure 1 Distribution of VALUE. The figure shows that the PatVal-EU patent VALUE distribution is skewed. Since the difference in the logs of the boundaries of the intervals is roughly constant, the distribution in the figure is an approximation of a log-normal. Even the log-normal distribution looks skewed.

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Table 1 Description of variables employed in the analysis

Variable	*Description*
VALUE	Index equal to 1–10 for the following PatVal-EU classes of patent values: ⩽€30K; 30–100K; 100–300K; 300K–1M; 1–3M; 3–10M; 10–30M; 30–100M; 100–300M; ⩾300M
VALUEM	Mid point of VALUE (15K; 65K; 200K; 650K; 2M; 6.5M; 20M; 65M; 200M; 650M[a])
CITES	# of forward citations to the patent within 5 years after the publication of the patent (usually 18 months after the priority date), including citations to equivalent patents
REFS	# of backward references in the patent
CLAIMS	# of claims of the patent at the moment of grant
STATES	# of designated European countries in which the patent is applied for
CITES0–5	Six dummies for CITES = 0; 1; 2; 3–5; 6–8; or 9, corresponding to the following percentiles of the CITES distribution of all the EPO patents with priority date 1993–1997 granted by 2003 and with first inventor in our eight countries (49,941 patents): 1–45; 46–70; 71–83; 84–96; 96–98; ⩾99.
VALUE⩾5, VALUE⩾6, VALUE⩾7	Three dummies equal to 1 if VALUE ⩾5, 6 or 7, corresponding to 17.5, 7.8, or 3.9% of the 8217 PatVal-EU patents for which data on VALUE are available.
Country dummies	Eight dummies for address of the first inventor in Denmark, France, Germany, Hungary, Italy, Netherlands, Spain, UK
Application year dummies	Six dummies for application years 1993–1998[b].
Technology dummies	Thirty technological area dummies obtained by converting the IPC classes of the patent using the ISI-INPI-OST concordance list[c].
IPC 3-digit dummies	117 dummies for the main IPC 3-digit class of the patent

[a]For the last interval of VALUE, VALUEM was set equal to the mid-point of 300–1000M.
[b]PatVal-EU sampled patents with priority date 1993–1997, but applications may exhibit a later date because applicants may patent first in their national countries. Hence, for some PatVal-EU patents application year is 1998.
[c]See Giuri *et al.* (2007) and Schmoch and Kirsch (1993) for details and references on the ISI-INPI OST concordance list. The 30 technology areas are: Agricultural and food processing, machinery and apparatus; Agriculture, food chemistry; Analysis, measurement, control technology; Audio-visual technology; Biotechnology; Chemical and petrol industry, basic materials chemistry; Chemical engineering; Civil engineering, building, mining; Consumer goods and equipment; Electrical devices, electrical engineering, electrical energy; Engines, pumps, turbines; Environmental technology; Handling, printing; Information technology; Machine tools; Macromolecular chemistry, polymers; Materials processing, textiles, paper; Materials, metallurgy; Mechanical Elements; Medical technology; Nuclear engineering; Optics; Organic fine chemistry; Pharmaceuticals, cosmetics; Semiconductors; Space technology weapons; Surface technology, coating; Telecommunications; Thermal processes and apparatus; Transport.

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Table 2 Descriptive statistics

	Mean	*St. Dev.*	*Min*	*P25*	*Median*	*P75*	*Max*	*N .obs.*
VALUE	3.864	1.831	1	3	4	5	10	8217
VALUEM	10887.14	64647.08	15	200	650	2000	650,000	8217
CITES	1.449	2.228	0	0	1	2	40	8217
REFS	4.38	2.241	0	3	4	6	18	8217
CLAIMS	10.957	7.27	1	6	10	14	131	8217
STATES	9.009	4.92	1	5	7	13	19	8217
DE	0.373	0.484	0	0	0	1	1	8217
DK	0.052	0.223	0	0	0	0	1	8217
ES	0.016	0.126	0	0	0	0	1	8217
FR	0.132	0.339	0	0	0	0	1	8217
HU	0.004	0.065	0	0	0	0	1	8217
IT	0.128	0.334	0	0	0	0	1	8217
NL	0.127	0.333	0	0	0	0	1	8217
UK	0.166	0.372	0	0	0	0	1	8217
Applic. year 93	0.025	0.157	0	0	0	0	1	8217
Applic. year 94	0.28	0.449	0	0	0	1	1	8217
Applic. year 95	0.254	0.436	0	0	0	1	1	8217
Applic. year 96	0.228	0.419	0	0	0	0	1	8217
Applic. year 97	0.159	0.366	0	0	0	0	1	8217
Applic. year 98	0.054	0.225	0	0	0	0	1	8217

Descriptive statistics computed for the 8217 PatVal-EU patents for which VALUE is available. Descriptive statistics for CITES1–5 and for VALUE⩾5–7 are straightforward. The 8217 PatVal-EU patents employed in our analysis are spread fairly well across the industry and IPC three-digit dummies.

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Table 9 Testing the impact of CITES, REFS, CLAIMS, and STATES, OLS regressions, dependent variable log(VALUEM)

	Model I	*Model II*	*Model III*	*Model IV*	*Model V*	*Model VI*
CONST	6.614***	6.374***	6.063***	5.678***	5.066	5.823***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Country dummies	Yes	Yes	Yes	Yes	Yes	Yes
Technology class dummies	Yes	Yes	Yes	Yes	Yes	Yes
Application year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Log(1+CITES)	—	0.396***	0.385***	0.361***	0.343***	0.356***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log(1+REFS)	—	—	0.198***	0.171***	0.158**	0.137**
			(0.001)	(0.006)	(0.010)	(0.030)
Log(CLAIMS)	—	—	—	0.193***	0.171***	0.170***
				(0.000)	(0.000)	(0.000)
Log(STATES)	—	—	—	—	0.372***	0.395***
					(0.000)	(0.000)
IPC 3-Digit Dummies	—	—	—	—	—	Yes
R^2	0.065	0.079	0.080	0.083	0.092	0.113
Change in R^2	—	0.014	0.001	0.003	0.009	0.021
N. Observations	8217	8217	8217	8217	8217	8217

P-values based on robust standard errors in parentheses. *$P<10\%$; **$P<5\%$; ***$P<1\%$. All regressions use sampling weights, and observations are clustered by patent applicants. The table shows that progressive addition of citations and other indicators as regressors improves fit by a few percentage points. Citations improve fit by 1.4%, which is just slightly higher than the contribution of the other three indicators combined. Although statistically significant, the overall impact of the indicators is small. Even after including the IPC 3-digit dummies we can only explain 11.3% of the patent value.

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