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Knowledge Management, Innovation and Intellectual Capital for Corporate Value in the United States*

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Abstract: The dynamic capabilities of 74 publicly listed U.S. companies are examined to determine their knowledge management's effects on shareholder value. R&D practices, patenting and intellectual capital are examined in a cross-sectional and longitudinal analysis to offer insights into the temporal dynamics of managerial decision-making and create new knowledge about time lags in returns on innovation and intellectual capital management. From the accounting perspective, the findings are highly relevant for knowledge productivity. The results indicate that innovation and intellectual capital are beneficial for corporate value and that firm size, debt level and industry matter for the outcome. The paper highlights areas of success and in need of further development in the period during and after the "Dot-com crisis" and suggests increased awareness of long-term thinking in innovation by showing how previous investments in innovation act on future corporate value.
Key words: dynamic capabilities; innovation; managerial capital; shareholder value
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1. Introduction

The competitive advantage of firms has long been a core issue within management accounting research. As a theoretic concept, the term competitive advantage targets the capacity of an organization to capitalize on its surrounding economic environment on basis of its created value. Since the 1980s, the answers to competitiveness have been sought for within the increasingly larger difference between the market value of firms (i.e., the appraisal of investors) and their book-value of equity (i.e., the value declared in financial statements). This unexplained variance between the market capitalization of a firm and its replacement value of tangible assets is often attributed to value generated through the management of intellectual capital (Hall, 1992; Edvinsson & Malone, 1997; Stewart, 1997; Bukh et al., 2005; Lev et al., 2005; Ittner, 2008).

In spite of improvements in accounting, it is still not a matter of common sense how innovation should be classified and measured in order to extract the most information about achievements from corporate disclosure data. Such aspects need to be coherent in order to be comparable and unawareness of the temporal dynamics of knowledge may result in uninformed investments and decisions, which can have costly consequences for the firms

* Data Availability: The data used in this study are secondary in nature and can thus not be directly shared by the author. Data are available from the public sources identified in the paper.

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and their investors.

In this paper, the heterogeneity of the companies is examined on basis of the innovation and intellectual capital management practices of the firms. The unique contribution of this study is its incorporation of several theoretical and scientific shortages identified through reviews of existing literature and previous research studies into one and the same analysis. To derive new findings within firm valuation, these shortages are evaluated empirically in relation to the raised theoretical assumptions in the long-run operability of innovating firms.

The first advantage of this study lies within the fact that investments in innovation are examined in relation to the existing discrepancy of market-to-book values with support of modern management theory in longitudinal terms. Foss and Ishikawa (2007) argue that the greatest shortages of the resource-based view are that it lacks a dynamic perspective and that it builds on the competitive equilibrium (i.e., "perfect competition" model), generating economic rents based on resources' best abilities. An approach based on capital theory is an essential part of the dynamic resource-based view and particular "specialized resource combinations" are possible to develop as products of the judgment. The judgment of managers in itself is a necessary complementary resource to not only compete on basis of price, but on basis of "asymmetric information" as an outcome of a process of searching and judging in relation to the market over time.

Ittner (2008) argued that it is rarely known how long it takes before changes in intangible assets yield economic results, making it therefore difficult to specify the appropriate time lag in empirical models. Many quantitative studies analyze the relationship between investments in intangibles and improved performance with firm outputs such as profits, productivity and sales without taking into consideration the effects of the time lags which exist between investments and their returns. In response, the proposed model incorporates estimation of log-differenced R&D data, which is equivalent to estimating growth rates expressed as estimates of the slope coefficient (World Bank, 2013). The suggested solution relates previous investments to current values to account for the delay on innovation returns, offering an improvement in relation to most previous studies of this kind. By defining novel effects in data which are widely available to the stakeholders, concerns of return on investment from R&D and the longevity of intangible assets are sorted out. The analysis treats flows of knowledge in relation to knowledge stocks (patents), allowing for insights within the efficiency of innovation in generating financial returns.

Lev et al. (2005) outlined common problems within research and other voluntary works on intellectual capital, namely "the lack of harmonization (comparability) among firms, industries, or different years for which the data are published". The third advantage of this analysis is hence that the competitiveness of current and previous investments in R&D is studied in detail in relation to intellectual capital and shareholder value. The U.S. companies included in this study are publicly listed and well-developed within the area of intellectual capital management[1] and the data comprise seven consecutive years, with no missing values.

The fourth advantage of this study lies in its research design and statistical modeling of Cobb-Douglas knowledge-based production systems, where the interaction of innovation and intellectual capital allows for extending the understanding about the value-generation process.

This study makes several contributions to existing literature. The first one involves novel research findings that amend a common methodological issue of prior studies, namely the resource-based view conflating its

[1] "With respect to fourteen years of data, the top ten countries in the overall ranking list are, in order, Finland, Sweden, Switzerland, Denmark, the USA, Singapore, Iceland (2007 and 2008 data are missing, very likely due to the 2008 financial crisis), the Netherlands, Norway and Canada." (Edvinsson & Lin, 2011, p. 22).

prescriptions of "best-usage of resources" with their effects. By separating intellectual capital from the effects of innovation, this huge shortcoming is overcome, adding indications of "how" to the body of theory. Second, this study contributes to management accounting theory through new and convincing evidence of the need for increased awareness of the long-term planning horizon in innovation by outlining causes to differences in the market value of firms across firms of different sizes, debt levels and industrial types. Third, the improved measurement of variables presents an accurate and complete picture of both the time and space dimensions of knowledge management, where delayed returns on innovation are successfully linked to present values, facilitating hence the estimation of future returns on knowledge-based investments. Fourth, the applied production function uses a multiplicative error structure based on the core assumption of intellectual capital theory that non-zero contributions of the respective managerial capitals are not value-generating in practice.

The remainder of this paper is organized as follows. State-of-the-art literature is discussed in the second section, along with the hypotheses of this analysis. The data and variable measurement are discussed in the third section and in the fourth section, empirical evidence is provided to the contributions of innovation and intellectual capital to firm value. The fifth section concludes the paper and suggests future research directions.

2. Literature Study and Hypothesis Development

Across studies which span over the raised issues, the existing evidence is contradictory. It is therefore of great importance to the research domain that new findings are produced within the topic. The research design is developed after observing previous findings in strategic management and intellectual capital theory which are of direct importance to the value evaluation process, with a focus on the longevity of investments. The theoretical perspectives adapted in this study reflect the corporate valuation concept and sustainability in the long-run operability of the companies. With support of the resource- and knowledge-based views, this study looks into the firms' costs, arguing that cost advantages are beneficial, since used resources must be made profitable. Second, this analysis focuses on understanding how corporate value is affected by the practices of knowledge-based activities and the outcomes of decision-making in relation to innovation by reviewing related theories and previous research studies.

2.1 Perspectives on Corporate Value

Drnevich and Shanley (2005b) state that a firm's profitability in a given market depends on (a) market-level economics, (b) the ability of individual firms to generate revenues to cover their costs and (c) the relative skills of firms to do this more efficiently than their competitors. Competitive advantage is thus a matter of understanding of a firm's production efficiency at different levels. The authors distinguish between five different areas of creating competitive advantages: (a) firm resources and capabilities, (b) firm strategy and managerial actions, (c) competitor resources, capabilities, behavior and actions, (d) consumer demand and behaviors and (e) industry/market macro-level structural and contextual characteristics. Value creation roots within a firm's activities, which are important for a firm's success, being particularly critical in highly competitive or changing markets in which the firms must maintain their competitive advantages. At the same time, new value-creation prospects must be assured for future profits and sustainability. The consumers choose the firm which gives them the greatest surplus, whilst the firm needs to generate profit by balancing its price in relation to its costs.

Several studies have investigated these propositions further. Mackey and Barney (2005) affirmed the need of several levels: (a) the individual-level resources controlled by the manager, (b) the industry-level competitive advantages derived from their resources and (c) the market-determined ability of a manager to appropriate the rents these competitive advantages generate. Value and competitive advantages are generated by rare and inimitable management skills, but the market will generally allocate these resources imperfectly across competing firms. The amount of rent that can be generated depends hence on the impact of heterogeneous management skills and imperfectly competitive labor markets on firm value.

Peteraf (2005) writes that the resource-based view distinguishes between sustainable and regular competitive advantages in such a way that if it is an imitable competitive advantage, it is not sustainable and therefore short-lived. By changing the definition of competitive advantage from terms of profitability to terms of relative value created, the definition of competitor is made more tangible. Thus, the old concept of competitive advantage in which a firm earns more profit than the other firms with which it competes is changed to the definition of "a firm having a competitive advantage if it is able to create more economic value than the marginal (breakeven) competitor in its product market". The notion of total value remains in agreement with Drnevich and Shanely (2005b), i.e., that total value created (consumer and producer surplus) captures the benefits to society of producing net of the economic costs. The resource-based view can therefore serve as a process-oriented approach instead of a content-oriented one through central internal focus on resources and capabilities and their connection to strategic decision-making, being hence suitable to analyze firms dynamically across time, although in its original form, it was a static equilibrium model of creating and sustaining competitive advantages.

In a subsequent review of these articles, Drnevich and Shanely (2005a) specify that while the dynamism of the firms and of the environment includes changes of resources and capabilities along time, it is within these phenomena where new business opportunities arise and value can be created. Resources may persist for a firm and their value might change to positive or negative and therefore, strategic management research should address the trajectories by which resources change, due to internal dynamics or in response to the environment through more focused and longitudinal designs.

In response, I (null) hypothesize that due to the heterogeneity of the companies' production systems and knowledge available, the generated value depends on their decision-making perspective applied in relation to time:

H1: the effects of innovation do not depend on time-focused decision-making.

Rejection of this hypothesis establishes a linkage between a firm's profitability and the benefits of its stakeholders by correcting the often misleading short-term focus in corporate performance due to unawareness of the time-lags of return on innovation.

2.2 Dynamic Capabilities

Teece et al. (1997) defined the dynamic character of skill acquisition, management of knowledge and know-how by stating that the main driving force of competitive advantages and value creation lies within the internal technological, organizational and managerial processes of the firms. Core competences must be distinctive from the competitors' and difficult to replicate in order to be efficient. Increasing returns are usually generated from network externalities, presence of complementary assets, supporting infrastructure, learning by using and scale economies in production and distribution. Likewise, Bukh et al. (2005) argue that the competitiveness of companies no longer concerns their positioning in the market vis-à-vis with the competitors, but the understanding of internal resource architectures, capabilities and competencies. Cheng et al. (2010) found that innovative capacity and efficient operating processes are antecedent factors which represent invested resources. Human and customer capitals are important in the competitive advantages of a company and affect corporate performance directly, whilst innovation and processes affect corporate performance indirectly through maintainable customer relationships and human value-added resources. Harlow and Imam (2006) found that firms which have a greater tacit knowledge index also have a greater degree of innovation and a better financial outcome, regardless of their strategic orientation.

I hence (null) hypothesize that:

H2: R&D practices and patents have no beneficial effect on corporate value.

2.3 Returns on Knowledge Management

Arthur (1994) found that heavily resource-based parts of an economy usually experience diminishing returns, whilst knowledge-based ones experience increasing returns, often based on investments in R&D and location, turning mass-production into an insecure income source. Roos et al. (1997, p. 107) agree with this fact, specifying that financial capital is characterized by diminishing returns, while intellectual capital enjoys increasing returns to scale.

Several studies have since then indicated the presence of diminishing returns even in knowledge-based production systems. Reed et al. (2006) found that intellectual capital's relation to financial performance is industry-specific and that intellectual capital can be subject to diminishing returns, explained in terms of bureaucracy impacting on long-run performance through high levels of social and organizational capital. Tayles et al. (2007) found that firms with higher knowledge profiles and competencies available did not experience lower capital costs, supporting the information asymmetry theory and leading to the consequence that investors are not always able to observe a company's competitive positioning through information disclosures, leading them to rely more heavily on the better understood value of tangible assets. Hence, intellectual capital helps combat uncertainty, but these firms were not less susceptible to stock market falls or to investor overreaction.

Quinn et al. (1996) write that growing organizations seemed for a while to involve diseconomies of scale and the only ways in which value could be created was through more intense training or work schedules as the competitors and by increasing the number of associates supporting each professional. As new technologies and managerial approaches evolved, firms became better at capturing and leveraging intellectual resources.

I hence (null) hypothesize that:

H3: intellectual capital-based operating processes are not subject to value erosion over time.

2.4 Knowledge-based Production Systems and Synergetic Effects

Chen and Wang (2010) found that high-performance systems have a significant impact on both radical and incremental innovation capabilities within companies, where high-performance work systems are positively associated with intellectual capital, intellectual capital is positively related to innovative capabilities and intellectual capital totally mediates the effects of innovation on firm performance. Yang and Kang (2008) found that internal and external resources (innovation and customer capitals) have different effects on firm performance than their interaction. The impact of innovation is important in both high-technological and low-technological firms and is industry independent. The results indicated synergistic effects due to the interaction of innovation and customer capital only in high-technological firms and managers should therefore avoid over-investing in contexts where resources cannot be leveraged through configuration, complementarity or integration since the efficiency of external capital is limited.

I hence (null) hypothesize that:

H4: no synergetic effects of innovation and intellectual capital increase corporate value.

3. Data and Variable Measurement

3.1 Sample Selection

Financial data were collected from the databases Orbis and Compustat. The selection criteria for selecting companies from Orbis were that the companies had available information about founding year, managed intangibles, be publicly listed and had reported their number of employees and R&D expenditures during the period of interest. Data were selected for ten years, the maximum possible, ranging from 2001 to 2010. Approximately 240 companies matched this search step, but many of them had missing data. The remaining companies were matched with available advertising data, research and development expenditures and selling general and administrative expenses from Compustat for the period of 1999 to 2007, so that the lagged R&D variable could be calculated. This search step limited the relevant companies to approximately 100. The relevance of these selection criteria is based on the literature review in the previous section. The selected companies have a common factor of relying on both internal innovations (R&D practices and management of intangibles)and external capital management (advertising), increasing hence the adequacy of the sample. The last step consisted of patent application data from the U.S. National Patent Bureau (USPTO, 2013).

The remaining companies were classified by their NAICS 2007 core industrial code. The distribution of observations varied across the industrial sectors and therefore, only sectors which contained a minimum of 30 observations[2] were kept for the empirical analysis. The final sample consists of 74 companies, from which 60 are manufacturing and 14 are non-manufacturing companies, covering six industrial sectors (see Appendix 1 for a complete list of the included companies). The first four sectors are manufacturing firms (chemicals, computer and electronic products, machinery and miscellaneous manufacturing), while the last two are service firms (professional scientific and technical services and publishing). The panel data are balanced and the total amount of observations is 518, ranging from 2001 to 2007.

3.2 Measurement of Output

3.2.1 Shareholder Value

Following James Tobin's Nobel awarded discovery "q", the concept of Tobin's Q is widely applied as an intellectual capital measurement of hidden value in "market-to-book" studies (Stewart, 1997; Wang & Chang 2005; Cheng et al., 2008; Yang & Kang, 2008). Tobin's Q is calculated as the ratio of market-to-book values of the companies and represents the incentive of maximizing value for the shareholders and the firms themselves.

3.3 Measurement of Inputs

3.3.1 Intellectual Capital

This study incorporates a commonly practiced and converged view of three forms of intellectual capital: human capital, customer capital (also known as relational capital) and structural capital (also known as organizational capital), in agreement with, i.e., the works of Saint-Onge (1996), Edvinsson and Malone (1997) and Stewart (1997).The respective variables are calculated as financially-derived metrics based on the companies' annual reports. Cheng et al. (2008) and Wang (2008) defined human capital as either net sales or net income per employee. It is herein argued that the net sales value per employee is more interesting than the income, since the latter is a pure output. Structural capital is calculated as net sales per total assets, to define the process capabilities

[2] This number is chosen on basis of the "central limit theorem", where a minimum of 30 observations are required for a sample distribution to be considered as reasonably normally distributed (Mendenhall & Sincich, 2011, p. 31).

of a firm to generate output in relation to its assets. In the case of customer capital, the variable represents the costs dedicated to obtaining the realized sales levels and it is herein argued that the selling general administrative expenses[3] per net sales measurement it is a suitable indicator of customer-related investments.

3.3.2 Innovation

Abdih and Joutz (2005) used patent applications as a measure of invested knowledge and technological change occurring in companies. The authors argue that patents are better fitted to represent innovation in R&D-based growth models than R&D expenditures since their investments are knowledge-driven. Furthermore, the suitable form is to use patent applications instead of issued patents since these might be subject to a time delay when measuring innovativeness. An index of the companies' annual patent applications is hence applied in the analysis along with the traditional measure of investment R&D expenditures. The third construct was adopted from the work of Hsu and Wang (2010), where the average percentage in R&D expenditures over the previous three years was used to capture the magnitude of change in a firm's innovation resource deployment. The authors argue that this is a more stable measure than contemporaneous R&D expenditures and it is hence included in the innovation variables.

3.3.3 Labor

Besides capital, labor plays an important role within production functions. Labor is calculated as commonly practiced, the number of employees.

3.4 Measurement of Quantities and Prices

In order to calculate the optimal levels of investment, the quantities and prices of the respective investments are derived for the respective variables. Shareholder value quantity is calculated as the number of common shares issued and the share price is calculated as market value divided by the number of issued shares. The operating process quantity is calculated as the sum of sales capacity (human, customer and structural capitals) and the price is defined as cost of goods sold. The innovation quantity is expressed as the index of applied patents and the price is calculated as current R&D expenditures alternatively the three-year averaged and lagged R&D expenditures. The number of employees represents the quantity of labor and the price is defined as selling general and administrative expenses. To guarantee a reliable comparison, all calculations are per employee.

3.5 Measurement of Control Variables

3.5.1 Industrial Area

Several prior studies have indicated the importance of industry for intellectual capital management (Arthur, 1994; Lockett & Thompson, 2001; Leiblein & Madsen, 2007; Yang & Kang, 2008). Industrial area is therefore accounted for by distinguishing between the non-manufacturing and manufacturing firms by type.

3.5.2 Firm Size

Leiblein and Madsen (2009) and Zéghal and Maaloul (2010) have documented that size is significantly and negatively related to performance, while Hsu and Wang (2010) demonstrated that size has a positive effect on corporate performance. Firm size is therefore included in the study and is calculated as book value over total assets.

3.5.3 Firm Age

Wang and Chang (2005) and Hsu and Wang (2010) found that age exhibits negative effects on performance

[3] "Selling general and administrative expenses" excludes the cost of goods sold (Compustat definition). It is herein specifically chosen since the "cost of goods sold" represents the price of sales in a dedicated analysis.

and Leiblein and Madsen (2009) identified a positive importance of age since the innovating ability of firms increased with experience. Firm age is calculated as the number of years since the firm was incorporated.

3.5.4 Firm Leverage

Hsu and Wang (2010) and Zéghal and Maaloul (2010) found that leverage acts negatively on firm value. When a company runs short of financial resources due to, e.g., unexpected expenditures, further innovation is hindered and liquidity diminishes. The debt level is hence included and is calculated as total long-term interest-bearing debt over total shareholder's equity.

3.6 Regression Models

The Cobb-Douglas production function is widely applied in analyses of corporate production based on inputs and outputs. A Cobb-Douglas production function (Cobb & Douglas, 1928), $y = AK^{\alpha}L^{\beta} + \varepsilon$ can be an appropriate representation of the production systems since in reality, the effects of the inputs might be limited, just as described in some of the previously discussed studies. Yet, the production function is not an isolated equation but rather embedded in a system of equations derived from hypotheses about the behavior of entrepreneurs and market structures. The stochastic errors might therefore not be independent of each other and the estimation procedure should recognize this[4].

A non-linear representation $y = f(K,L) = AK^{\alpha}L^{\beta}$ is hence proposed and it can be solved through logarithmic transformation and multiplicative errors[5], so that $y = AK^{\alpha}L^{\beta}\varepsilon^{u}$. This form is commonly used when it is suitable to express change as a percentage instead of a constant amount, which is highly adequate in this study. Nevertheless, multiplicative error modeling reflects the intellectual capital dynamics by supporting a non-zero combination of all specified inputs (Saint-Onge, 1996; Edvinsson & Malone, 1997; Stewart, 1997). The Cobb-Douglas multiplicative function is suitable since the function is asymptotic to the axes no matter what level of output is chosen and is therefore homothetic, not making it possible to produce anything without all the specified inputs available[6]. Non-homogenous functions which include higher-order terms (squares and cross-products) like the translog function are recommended when analyzing synergetic effects and when the restrictions imposed by the regular Cobb-Douglas form might be unrealistic. All three function forms are therefore considered in the analysis.

The knowledge-based Cobb-Douglas production function (1) is thus represented with a multiplicative error term in a generic unobserved effects model (i.e., panel data model):

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[4] A restricted Cobb-Douglas function applied on firms in a competitive market assumes that the relative prices of the factors are the same for all firms (cross-sectional) or the same over time (time series), where the ratio of the inputs remains constant, making it impossible to reveal anything about the inputs' substitution possibilities. When entrepreneurs decide inputs based on price references, these prices are taken for given and the inputs are chosen accordingly. In this case, the inputs are not "exogenous" to the entrepreneur, but "endogenous" (as determined in the system of equations). All these different aspects might have alternative error specifications (multiplicative or additive) and there might be a possible interdependence of errors (Heathfield & Wibe, 1987, pp. 159-160).

[5] A multiplicative non-linear expression translates to a linearized form $\ln(y) = \ln(A) + \alpha\ln(K) + \beta\ln(L) + \ln(\varepsilon)$ in order to be solvable with ordinary least squares. A common difference between the additive and multiplicative error-estimation approaches is that the relative marginal elasticities of α_K and β_L do not usually agree in magnitude (Hrishikesh, 2008, pp. 10-11). Fitting the model with generic additive errors assumes that the variability around the model is the same, i.e., homoscedastic. Yet, the normal distribution assumption of the errors of the function, $y = AK^{\alpha}L^{\beta} + \varepsilon$, where ε is a random error, does not always carry over efficiently to its expected stochastic representation.

[6] Logarithmic transformation is monotonically increasing. In general, any homothetic function (such as Cobb-Douglas) is a monotonically increasing transformation of a homogeneous function. This characteristic comes with the following hidden restrictions: a) all isoquants of a homothetic function are forced to be parallel to each other, b) the marginal rates of technical substitution between input and output are forced to be constant along the ray from the origin, c) the scale elasticity for homothetic production functions depends only on the output level and d) the elasticity of substitution is 1 and the constant elasticity of scale is $1/(1 + \rho)$ (Hrishikesh, 2008, p. 28).

$$Y_{it} = A\, HC^{\beta 1}{}_{it}\, CC^{\beta 2}{}_{it}\, SC^{\beta 3}{}_{it}\, LaggedR\&D^{\beta 4}{}_{it}\, R\&D^{\beta 5}{}_{it}\, Patents^{\beta 6}{}_{it}\, Labor^{\beta 7}{}_{it}\, Size^{\beta 8}{}_{it} Age^{\beta 9}{}_{it}\; Leverage^{\beta 10}{}_{it} Industrial\ Area^{\beta 11}{}_{it} u^{u}{}_{it} + e_{it} \quad (1)$$

By taking the natural log of both sides of the considered model, the linearized restricted Cobb-Douglas production function becomes:

$$\begin{aligned} \ln(Tobin's\ Q)_{it} = {} & \ln(\alpha)_{it} + \beta_1 \ln(HC)_{it} + \beta_2 \ln(CC)_{it} + \beta_3 \ln(SC)_{it} + \beta_4 \ln(Lagged\ R\&D)_{it} \\ & + \beta_5 \ln(R\&D)_{it} + \beta_6 \ln(Patents)_{it} + \beta_7 \ln(Labor)_{it} + \beta_8 \ln(Size)_{it} \\ & + \beta_9 \ln(Age)_{it} + \beta_{10} \ln(Leverage)_{it} + \beta_{11} Industrial\ Area \\ & + \ln(u^{u}{}_{it} - 1_{it}) + e^{\varepsilon}{}_{it} \end{aligned} \quad (2)$$

The dependent variable, i.e., the output, is Tobin's Q. The independent variables represent investments made in operating processes and sales in terms of human (HC), customer (CC) and structural capitals (SC). Innovation is represented by the knowledge-progress terms three-years lagged research and development expenditures (Lagged R&D), research and development expenditures (R&D) and the applied patents index (Patents). These managerial capitals and investments represent the companies' knowledge flows, whilst the applied patents indicate the existing knowledge stocks. Labor is represented as the number of employees and the control variables are size (ibid), age (ibid), debt level (Leverage) and type of firm (Industrial Area).

To form the unconstrained Cobb-Douglas production function, interaction terms are added to the restricted Equation (2):

$$\begin{aligned} \ln(Tobin's\ Q)_{it} = {} & \ln(\alpha)_{it} + \beta_1 \ln(HC)_{it} + \beta_2 \ln(CC)_{it} + \beta_3 \ln(SC)_{it} + \beta_4 \ln(Lagged\ R\&D)_{it} \\ & + \beta_5 \ln(R\&D)_{it} + \beta_6 \ln(Patents)_{it} + \beta_7 \ln(Labor)_{it} + \gamma_8 \ln(HC) \ln(CC)_{it} \\ & + \gamma_9 \ln(HC)_{it} \ln(Lagged\ R\&D)_{it} + \gamma_{10} \ln(HC)_{it} \ln(R\&D)_{it} \\ & + \gamma_{11} \ln(HC)_{it} \ln(Labor)_{it} + \gamma_{12} \ln(HC)_{it} \ln(Patents)_{it} + \gamma_{13} \ln(HC)_{it} \ln(SC)_{it} \\ & + \gamma_{14} \ln(CC)_{it} \ln(Lagged\ R\&D)_{it} + \gamma_{15} \ln(CC)_{it} \ln(R\&D)_{it} \\ & + \gamma_{16} \ln(CC)_{it} \ln(Labor)_{it} + \gamma_{17} \ln(CC)_{it} \ln(Patents)_{it} + \gamma_{18} \ln(CC)_{it} \ln(SC)_{it} \\ & + \gamma_{19} \ln(Lagged\ R\&D)_{it} \ln(Patents)_{it} + \gamma_{20} \ln(R\&D)_{it} \ln(Patents)_{it} \\ & + \gamma_{21} \ln(Lagged\ R\&D)_{it} \ln(Labor)_{it} + \gamma_{22} \ln(R\&D)_{it} \ln(Labor)_{it} \\ & + \gamma_{23} \ln(Lagged\ R\&D)_{it} \ln(SC)_{it} + \gamma_{24} \ln(R\&D)_{it} \ln(SC)_{it} + \gamma_{25} \ln(SC)_{it} \ln(Labor)_{it} \\ & + \gamma_{26} \ln(SC)_{it} \ln(Patents)_{it} + \gamma_{27} \ln(R\&D)_{it} \ln(Lagged\ R\&D)_{it} \\ & + \gamma_{28} \ln(Labor)_{it} \ln(Patents)_{it} + \beta_{29} \ln(Size)_{it} + \beta_{30} \ln(Age)_{it} + \beta_{31} \ln(Leverage)_{it} \\ & + \beta_{32} Industrial\ Area + \ln(u^{u}{}_{it} - 1_{it}) + e^{\varepsilon}{}_{it} \end{aligned} \quad (3)$$

The translog alternative (4) is the same as the unrestricted Cobb-Douglas model (3), with square terms added for each variable. Appendix 2 presents expressions of relevance for various economic quantities derived for the respective Cobb-Douglas production functions.

3.7 Descriptive Statistics

Table 1 presents the log-transformed variables applied in the study. The means and the medians do not differ much and the logarithmic transformation normalizes the data well. The standard deviations of the variables are also small, except for labor. Yet, the values are within approximately two standard deviations so the value is within reliable perimeters.

Table 1 Descriptive Statistics of the Variables

Variable	Unit	Mean	Median	1stQ	3rd Q	Variance	Std. Dev.
Tobin's Q	Ratio	1.039	1.043	1.007	1.079	0.004	0.062
Human Capital	Ratio	1.773	1.769	1.607	1.901	0.034	0.186
Customer Capital	Ratio	0.912	0.928	0.900	0.949	0.011	0.106
Structural Capital	Ratio	0.652	0.644	0.621	0.686	0.002	0.039
R&D Expenditures	Million USD	2.123	2.107	1.839	2.371	0.120	0.347
Lagged R&D Expenditures	Percentage	1.284	1.279	1.249	1.313	0.007	0.083
Patent Applications	Index	4.937	4.691	4.625	5.004	0.344	0.587
Labor	Units	7.985	7.362	6.399	9.756	3.949	1.987
Size	Ratio	0.666	0.668	0.655	0.677	0.001	0.021
Age	Years	3.579	3.434	3.045	4.248	0.565	0.752
Leverage	Ratio	0.687	0.911	0.124	0.961	0.151	0.388

Note: All data in annual frequency and in logarithmic form. The sample consists of 74 innovating publicly listed U.S. companies and the observations range over the period 2001 to 2007.
Variable Definitions:
Tobin's Q: market value divided by book value;
Human Capital: net sales per employee;
Customer Capital: selling general and administrative expenses divided by net sales;
Structural Capital: net sales divided by total assets;
R&D Expenditures: all costs incurred during the year that relate to the development of new products or services;
Lagged R&D Expenditures: three-years lagged average percentage investments in R&D expenditures;
Patent Applications: index of patents applied;
Labor: number of employees;
Size: book value divided by total assets;
Age: current year - year of incorporation;
Leverage: long-term interest-bearing debt divided by total shareholder's equity.

The Pearson correlation matrix is presented in Table 2. According to these values, there is good reason to expect synergetic effects between most managerial capitals. Nevertheless, consistent with the hypotheses that intellectual capital and innovation are beneficial for corporate value, the correlations indicate significant relations to the dependent variable.

4. Results

Panel data regression analysis is first applied to define how innovation and intellectual capital interact in the long run to create value and which delays on investment can be expected. The marginal products of the inputs are thereafter calculated and contrasted to the results of the regression. The optimal levels of investments are lastly calculated to estimate the companies' efficiency of knowledge usage and development.

4.1 Panel Data Regressions of Corporate Value

The three Cobb-Douglas production functions (restricted, unrestricted and translog) were fitted to the data and tested for reliability. The unrestricted Cobb-Douglas function (3) is the only valid production function shape for this analysis based on results of nested F and interaction tests and it is validated with diagnostics tests recommended in the statistical package's documentation (Croissant & Millo, 2008), see Appendix 3 for details.

Table 3 presents the results from the regression analysis of the independent managerial capitals on Tobin's Q in the presence of firm size, age, leverage level and industrial type. The applied model is a random-effects model with Nerlove[7] transformation and time effects. The time effects account for a significant share of the total error

[7] See, e.g., Nerlove (1965, p. 6) for more details regarding Cobb-Douglas models.

variation, 98.80%, supporting the hypothesis of the investments being time-dependent and emphasizing the importance of a long-term perspective in business.

Table 2 Pearson Correlation Matrix of Regression Variables

Variable	Tobin's Q	HC	CC	SC	R&D	Lagged R&D	Patents	Labor	Size	Age	Leverage
Tobin's Q	1.000	-0.392***	-0.083.	0.519***	0.208***	0.107**	0.329***	0.524***	-0.312***	0.199***	0.209***
Human Capital		1.000	0.258***	-0.776***	-0.144***	0.151***	-0.470***	-0.907***	0.290***	-0.456***	-0.471***
Customer Capital			1.000	-0.240***	0.159***	0.198***	0.041	-0.234***	0.175***	0.062	-0.161***
Structural Capital				1.000	0.272***	-0.191***	0.548***	0.923***	-0.192***	0.562***	0.425***
R&D Expenditures					1.000	0.021	0.324***	0.236***	0.176***	0.101**	-0.028
Lagged R&D Expenditures						1.000	-0.043	-0.151***	0.053	-0.126***	-0.145***
Patents							1.000	0.623***	0.052	0.371***	0.220***
Labor								1.000	-0.171***	0.557***	0.483***
Size									1.000	-0.017	-0.379***
Age										1.000	0.298***
Leverage											1.000

Note: Significance is indicated by two-tailed tests at the 1 percent, 5 percent respectively 10 percent levels ($p < 0.01$ = "***", $p < 0.5$ = "**" and $p < 0.1$ = ".").
Variable Definitions:
Tobin's Q: market value divided by book value;
Human Capital: net sales per employee;
Customer Capital: selling general and administrative expenses divided by net sales;
Structural Capital: net sales divided by total assets;
R&D Expenditures: all costs incurred during the year that relate to the development of new products or services;
Lagged R&D Expenditures: three-years lagged average percentage investments in R&D expenditures;
Patent Applications: index of patents applied;
Labor: number of employees;
Size: book value divided by total assets;
Age: current year - year of incorporation;
Leverage: long-term interest-bearing debt divided by total shareholder's equity.

The results of the plm regression indicate the percentage change in output resulting from a one percent increase in an input holding all other inputs constant. Since the coefficients measure the elasticity of the output in relation to input changes, the negative signs indicate positive effects on corporate value and elastic capacities for absolute values bigger than 1. The individual effects of human capital (4.53%) and labor (0.54%) on shareholder value are negative for corporate value, while structural (-17.9%) and customer capitals (-6.89%) are value-giving. The effects of lagged R&D and R&D investments act both positively on shareholder value, -2.86 respectively -1.84%, just as patent applications (-1.29%). All results are hence significant and elastic except for labor, which is only significant (0.54%).

4.1.1 Synergetic Effects

The synergetic effects captured from innovation along the analyzed time period are representative, where previous R&D investments indicate several areas of profitability for corporate value, but not the current R&D expenditure measure. Lagged R&D expenditures are value-giving in interaction with human capital (-0.90%), patents (-0.01%) and with labor (-0.15%), but not with current R&D investments (0.53%). The significant synergetic effects of innovation indicate hence that current R&D investments and previous ones should be coordinated to attain maximum value. Patent applications yield two negative synergetic effects on corporate value, namely in interaction with customer (0.31%) and structural capitals (1.23%), suggesting that patenting applications practices could have been more efficient in relation to investments made. Although human capital was not profitable individually (4.53%), it has the biggest synergetic effect measured in interaction with structural capital (-5.00%). Customer and structural capitals act negatively together (10.22%), but the interaction of structural capital with labor is positive (-0.24%). All the significant synergetic effects are hence inelastic except for the value measured between human and structural capitals. In spite of this, the values are clearly indicative of the time dependency of returns on innovation and the importance of knowledge capital for firm value.

Table 3 Random-Effects PLM (Cross-sectional and Longitudinal) Regression of Innovation on Shareholder Value (Tobin's Q)

	Parameter Estimate	Std. Error	t-value	Pr(>|t|)
β_0	11.011 **	3.653	3.0140	0.0027134
β_{HC}	4.535 **	1.585	2.8618	0.0043948
β_{CC}	-6.895 *	2.766	-2.4922	0.0130284
β_{SC}	-17.901 **	6.358	-2.8154	0.0050705
$\beta_{LAGGED\ R\&D}$	-2.858 **	0.866	-3.3002	0.0010373
$\beta_{R\&D}$	-1.839 *	0.829	-2.2176	0.0270425
$\beta_{PATENTS}$	-1.292 ***	0.382	-3.3808	0.0007811
β_{LABOR}	0.543 **	0.198	2.7459	0.0062588
β_{HC*CC}	-0.485	0.773	-0.6283	0.5301270
$\beta_{HC*LAGGED\ R\&D}$	-0.902 .	0.505	-1.7841	0.0750327
$\beta_{HC*R\&D}$	-0.109	0.105	-1.0371	0.3001867
$\beta_{HC*LABOR}$	0.041	0.040	1.0237	0.3064722
$\beta_{HC*PATENTS}$	0.097	0.196	0.4956	0.6203850
β_{HC*SC}	-5.003 *	1.961	-2.5513	0.0110379
$\beta_{CC*LAGGED\ R\&D}$	0.200	0.154	1.3029	0.1932235
$\beta_{CC*R\&D}$	0.169	0.219	0.7715	0.4407820
$\beta_{CC*LABOR}$	-0.137	0.121	-1.1329	0.2578057
$\beta_{CC*PATENTS}$	0.312 .	0.183	1.7077	0.0883284
β_{CC*SC}	10.223 *	4.459	2.2929	0.0222810
$\beta_{LAGGED\ R\&D*PATENTS}$	-0.012	0.143	-0.0850	0.9322629
$\beta_{R\&D*PATENTS}$	0.051	0.085	0.6030	0.5468148
$\beta_{LAGGED\ R\&D*LABOR}$	-0.147 *	0.073	-2.0164	0.0443094
$\beta_{R\&D*LABOR}$	-0.019	0.027	-0.7201	0.4718383
$\beta_{LAGGED\ R\&D*SC}$	6.951 ***	1.680	4.1365	4.157^{e-05}
$\beta_{R\&D*SC}$	1.832	1.152	1.5908	0.1123079
$\beta_{SC*LABOR}$	-0.241 *	0.118	-2.0421	0.0416846
$\beta_{SC*PATENTS}$	1.235 *	0.561	2.2030	0.0280628
$\beta_{LAGGED\ R\&D*R\&D}$	0.530 *	0.207	2.5640	0.0106484
$\beta_{PATENTS*LABOR}$	-0.009	0.014	-0.5963	0.5512782
β_{SIZE}	-1.004 ***	0.118	-8.4886	2.565^{e-16}
β_{AGE}	0.001	0.004	0.1649	0.8691174
$B_{LEVERAGE}$	-0.015 *	0.006	-2.4288	0.0155122
$B_{NON-MANUFACTURING}$	0.018 **	0.006	2.9972	0.0028643
R^2	0.619	---	---	---
Adj R^2	0.580	---	---	---
P-value	$< 2.22^{e-16}$	---	---	---
F-statistic	24.6574 (32, 485 df)	---	---	---

Note: Significance codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.', 0.1 ' ', 1.
This table represents log-linear panel data regression results with random effects (Nerlove transformation and time effects) of the following equation:

$$\ln(\text{Tobin's Q})_{it} = \ln(\alpha)_{it} + \beta_1 \ln(HC)_{it} + \beta_2 \ln(CC)_{it} + \beta_3 \ln(SC)_{it} + \beta_4 \ln(\text{Lagged R\&D})_{it} + \beta_5 \ln(R\&D)_{it}$$
$$+ \beta_6 \ln(\text{Patents})_{it} + \beta_7 \ln(\text{Labor})_{it} + \gamma_8 \ln(HC) \ln(CC)_{it}$$
$$+ \gamma_9 \ln(HC)_{it} \ln(\text{Lagged R\&D})_{it} + \gamma_{10} \ln(HC)_{it} \ln(R\&D)_{it} + \gamma_{11} \ln(HC)_{it} \ln(\text{Labor})_{it}$$
$$+ \gamma_{12} \ln(HC)_{it} \ln(\text{Patents})_{it} + \gamma_{13} \ln(HC)_{it} \ln(SC)_{it} + \gamma_{14} \ln(CC)_{it} \ln(\text{Lagged R\&D})_{it}$$

$$+ \gamma_{15}\ln(CC)_{it}\ln(R\&D)_{it} + \gamma_{16}\ln(CC)_{it}\ln(Labor)_{it} + \gamma_{17}\ln(CC)_{it}\ln(Patents)_{it}$$
$$+ \gamma_{18}\ln(CC)_{it}\ln(SC)_{it} + \gamma_{19}\ln(Lagged\ R\&D)_{it}\ln(Patents)_{it}$$
$$+ \gamma_{20}\ln(R\&D)_{it}\ln(Patents)_{it} + \gamma_{21}\ln(Lagged\ R\&D)_{it}\ln(Labor)_{it}$$
$$+ \gamma_{22}\ln(R\&D)_{it}\ln(Labor)_{it} + \gamma_{23}\ln(Lagged\ R\&D)_{it}\ln(SC)_{it} + \gamma_{24}\ln(R\&D)_{it}\ln(SC)_{it}$$
$$+ \gamma_{25}\ln(SC)_{it}\ln(Labor)_{it} + \gamma_{26}\ln(SC)_{it}\ln(Patents)_{it}$$
$$+ \gamma_{27}\ln(R\&D)_{it}\ln(Lagged\ R\&D)_{it} + \gamma_{28}\ln(Labor)_{it}\ln(Patents)_{it}$$
$$+ \beta_{29}\ln(Size)_{it} + \beta_{30}\ln(Age)_{it} + \beta_{31}\ln(Leverage)_{it} + \beta_{32}\ \text{Industrial Area}$$

The industry effects are captured by industry dummies, where industry is based on NAICS 2007 codes and division in sectors by the definitions in the Compustat database. Appendix 1 presents the list of the companies included in this study and their industry classification.

The effects panel of the regression indicates a high share of time effects for the regression errors:

Variance		Std. Dev.	Share
Idiosyncratic	0.0001395	0.0118129	0.012
Time	0.0117305	0.1083075	0.988

Variable Definitions:

Tobin's Q: market value divided by book value;
Human Capital: net sales per employee;
Customer Capital: selling general and administrative expenses divided by net sales;
Structural Capital: net sales divided by total assets;
R&D Expenditures: all costs incurred during the year that relate to the development of new products or services;
Lagged R&D Expenditures: three-years lagged average percentage investments in R&D expenditures;
Patent Applications: index of patents applied;
Labor: number of employees;
Size: book value divided by total assets;
Age: current year - year of incorporation;
Leverage: long-term interest-bearing debt divided by total shareholder's equity.

4.1.2 Firm Characteristics and Industry

Size and leverage act positively on Tobin's Q, -1.00% respectively -0.02%, but age is not significant. The type of firm is also significant for firm value, where the manufacturing sector earned a plus of 0.02% along the analyzed time period in comparison to the service firms.

4.2 Marginal Products

The marginal products of the capitals and labor for the analyzed period are calculated as mean values and are presented in Table 4. The measured values indicate the increase in output resulting from one additional unit of the input, keeping the quantities of all other inputs fixed. The registered t-values are reliable for the variables found significant in the regression analysis, i.e., t-values higher than 1.96 represent a 95 percent confidence interval. The law of diminishing marginal returns indicates that at the optimum level the quantity of the respective input is zero, while negative values are beneficial for corporate value. A positive value indicates that the input could have been used more profitably.

The computed marginal products agree with the results of the regression analysis. All individual capitals are positive for corporate value, except for human capital (2.69) and labor (0.07), which could have been used more efficiently. Previous innovation investments are again more profitable than current R&D investments, -2.32 respectively -0.93 and only previous R&D investments indicate synergetic effects. The lagged R&D expenditures' interaction marginal values are profitable, with human capital (-0.42), patents (-0.002) and labor (-0.02), whilst an unprofitable marginal is indicated in relation to current R&D expenditures, 0.21. The patent applications are efficient individually (-0.27), but could have been used more profitably in relation to investments in structural(0.40) and customer (0.09) capitals, indicating that the application of patents does not necessarily include customer-oriented actions. The interaction between human and structural capitals is the most efficient one (-4.54). The synergy between customer and structural capitals is the most inefficient one (21.82). Structural capital and labor interact positively (-0.05). The marginal of size is beneficial (-1.57), just like the leverage level (-0.11). Age is not significant.

Table 4 Individual Marginal Products of the Independent Variables Regressed on Tobin's Q

Input	Marginal Products	t-value
HC	2.693 **	2.862
CC	-9.705 *	-2.492
SC	-28.588 **	-2.815
LAGGED R&D	-2.322 **	-3.300
R&D	-0.927 *	-2.218
PATENTS	-0.274 ***	-3.381
LABOR	0.074**	2.746
HC*CC	-0.404	-0.628
HC*LAGGED R&D	-0.419 .	-1.784
HC*R&D	-0.032	-1.037
HC*LABOR	0.003	1.024
HC*PATENTS	0.012	0.496
HC*SC	-4.544 *	-2.551
CC*LAGGED R&D	0.227	1.303
CC*R&D	0.121	0.772
CC*LABOR	-0.024	-1.133
CC*PATENTS	0.091 .	1.708
CC*SC	21.821 *	2.293
LAGGED R&D*PATENTS	-0.002	-0.085
R&D*PATENTS	0.005	0.603
LAGGED R&D*LABOR	-0.016 *	-2.016
R&D*LABOR	-0.001	-0.720
LAGGED R&D*SC	8.674 ***	4.136
R&D*SC	1.408	1.591
SC*LABOR	-0.052 *	-2.042
SC*PATENTS	0.404 *	2.203
LAGGED R&D*R&D	0.209 *	2.564
PATENTS*LABOR	0.000	-0.596
SIZE	-1.568 ***	-8.489
AGE	0.000	0.165
LEVERAGE	-0.114 *	-2.429

Note: Significance codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.', 0.1 '', 1.
The individual marginal products are calculated as mean values on basis of the plm regression's results.
Variable Definitions:
Tobin's Q: market value divided by book value;
Human Capital: net sales per employee;
Customer Capital: selling general and administrative expenses divided by net sales;
Structural Capital: net sales divided by total assets;
R&D Expenditures: all costs incurred during the year that relate to the development of new products or services;
Lagged R&D Expenditures: three-years lagged average percentage investments in R&D expenditures;
Patent Applications: index of patents applied;
Labor: number of employees;
Size: book value divided by total assets;
Age: current year - year of incorporation;
Leverage: long-term interest-bearing debt divided by total shareholder's equity.

4.3 Optimal Investment Analysis and Returns to Scale

The optimal levels of investment are presented in Table 5.

Table 5 Optimal Investment Analysis

	Q Labor	Q Intellectual Capitals	Q Patents
Optimal Values (current R&D Expenditures)	0.209	0.000001	10.33
Optimal Values (lagged R&D Expenditures)	0.018	0.00000012	13.283
Observed Values	7.985	0.064	0.647

Note: This table represents log-linear panel data regression results of the following equation of variable input quantities and firm characteristics:

$$\ln(\text{qTobin's Q})_{it} = \ln(\alpha)_{it} + \beta_1 \ln(\text{qLabor})_{it} + \beta_2 \ln(\text{qIC})_{it} + \beta_3 \ln(\text{qPatents})_{it} + \gamma_4 \ln(\text{qLabor})_{it}\ln(\text{qIC})_{it} + \gamma_5 \ln(\text{Labor})_{it}\ln(\text{qPatents})_{it} + \gamma_6 \ln(\text{qIC})_{it}\ln(\text{qPatents})_{it} + \beta_7 \ln(\text{Size})_{it} + \beta_8 \ln(\text{Age})_{it} + \beta_9 \ln(\text{Leverage})_{it}$$

in relation to the prices of the variable inputs (price of labor, price of intellectual capitals and price of patents applied with respect to corporate size, age and leverage) regressed on Tobin's Q. The observed values are calculated on basis of computed quantities and collected price data for the respective independent variables. All variables per employee and in logarithmic form.
Variable Definitions:
Quantity Tobin's Q: number of common shares issued;
Price Tobin's Q: market value divided by the number of common shares issued;
Quantity Labor: number of employees;
Price Labor: selling general and administrative expenses;
Quantity Intellectual Capital: the sum of human, customer and structural capitals;
Price Intellectual Capital: cost of goods sold;
Quantity Patent Applications: index of patents applied;
Price Patent Applications (1): current R&D expenditures;
Price Patent Applications (2): lagged R&D expenditures;
Size: book value divided by total assets;
Age: current year - year of incorporation;
Leverage: long-term interest-bearing debt divided by total shareholder's equity.

The prices are calculated in terms of both current and previous R&D investments. The observed values differ from both optimal levels, indicating that the quantities and costs of production are not optimally aligned to create maximum value. The used labor quantity (7.99) was much higher than the optimal ones (0.21; 0.02), supporting the previous finding of inelasticity of labor. Investments in intellectual capital (0.06), here calculated as the sum of all operating processes (human, customer and structural capitals), were higher than the optimal levels indicated in both relation to current and lagged R&D expenditures (0.000001; 0.00000012). The quantity of patents applied (0.65) is lower than both recommended values (10.33; 13.28). In general, the observed values are better aligned with the current R&D investment optimal calculation. This finding is again supportive of the argument that firms should apply long-term focus and temporal thinking about knowledge investments.

Table 6 presents the returns to scale and the costs for the analyzed period.

Table 6 Returns to Scale and Costs

Returns to Scale	-25.706
Costs	-3.672

Note: The returns to scale are calculated as the sum of the significant individual inputs' elasticity. The elasticity of cost is calculated as the reciprocal of the elasticity of scale. The results are based on the computed values of the log-linear panel data regression presented in Table 3.
Variable Definitions:
Tobin's Q: market value divided by book value;
Human Capital: net sales per employee;
Customer Capital: selling general and administrative expenses divided by net sales;
Structural Capital: net sales divided by total assets;
R&D Expenditures: all costs incurred during the year that relate to the development of new products or services;
Lagged R&D Expenditures: three-years lagged average percentage investments in R&D expenditures;
Patent Applications: index of patents applied;
Labor: number of employees;
Size: book value divided by total assets;

Age: current year - year of incorporation;
Leverage: long-term interest-bearing debt divided by total shareholder's equity.

The results indicate that the scale capacity is decreasing (-25.71). The costs were also negative for shareholder value (-3.67). These results are supportive of the previous optimal level calculations, where the measured quantities and prices were not found to be value-maximizing.

Figure 1 presents an isoquant of relation between the measured capitals and labor, where it is shown how the output grows when the levels of input increase in fixed proportions. Since the produced quantity level decreases as the level of inputs increases, decreasing returns to scale are indicated. Also, since the curvature of the isoquant is small and edgy, the possibilities of substitution between capital and labor are limited. This pattern is not cost-efficient since at other levels than the optimal, more of one factor is required to produce the same output but not less of the other. Nevertheless, it becomes more difficult to substitute one unit of capital with one unit of labor as we move from an intensive choice of capital to an intensive choice of labor, and labor is less flexible than the knowledge capital.

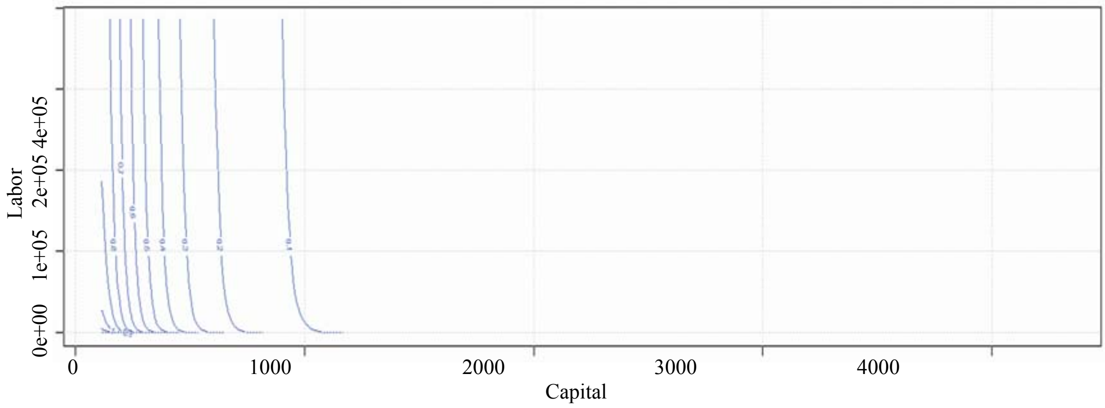

Figure 1 Production Function Level Curves Unrestricted Cobb-Douglas

5. Conclusions

This study examined the extent to which the returns on innovation and knowledge investments are explaining and creating corporate value on the market. The effects of innovation and intellectual capital on shareholder value are positive, both across firms and time.

Prior research rarely takes the temporal factor into account and this study contributes to the body of literature by documenting differences between three competing R&D measures (current R&D, three-year lagged R&D and an index of patent applications). The results are supportive of the hypothesis of effects of innovation being dependent of time-focused decision-making (hypothesis 1), as well as of innovation being beneficial for corporate value (hypothesis 2). The findings of Hsu and Wang (2010) are thus supported, since previous investments in R&D were more positive than current ones in explaining corporate value and indicated delayed returns on investment. Leiblein and Madsen's (2007) and Wang's (2008) findings of innovation being positive for performance could also be supported. In contrast with Abdih and Joutz (2005), patent applications were profitable for corporate value, although they were not optimally aligned with the costs of doing research.

By analyzing the companies' operations after the dot-com crisis, the study showed that knowledge-intensive companies can also be subject to value erosion along time (hypothesis 3) and that the service firms in this study experienced less efficiency than the manufacturing ones. These results are in agreement with Lockett and Thompson (2001). The importance of the long-term horizon and temporal effects are thus supported by the data and the results indicate that the firms repaired some of their losses incurred due to big costs of operations by innovating. This finding corresponds with Reed et al. (2006), who identified diminishing returns due to high levels of customer and structural capitals. Zéghal and Maaloul (2010) found that size and leverage were positive for market value, but this study recorded negative effects. In disagreement with Leiblein and Madsen (2009) and Hsu and Wang (2010), age was not significant.

The paper also outlines which synergetic effects were significant between innovation and intellectual capital, both positive and negative ones (hypothesis 4). Yang and Kang's (2008) results of the limitation of customer capital-based efficiency is hence partially supported, although the individual sales-based intellectual capital indicators were proved to be beneficial, just as some of the synergetic effects between intellectual capital and innovation respectively patenting practices. In agreement with Wang (2008), human capital acted negatively on business performance, while customer capital and labor acted positively.

The scope of the paper of analyzing innovation and intellectual capital in the temporal dimension and verifying the various components' contingency and their relations in generating value was supportive of intellectual capital and management theory as well as of the statistical modeling approach. A small limitation of this study arises because the measures used are mostly financially derived, although they represent the non-financial aspects of operating process quality and intensiveness of innovation. The explaining capacity of the model lies hence in extracting the decision-making dynamics and profitable management logic rather than focusing on the impacts of the effects as autonomous figures.

References:

Abdih Y. and Joutz F. (2005). "Relating the knowledge production function to total factor productivity: An endogenous growth puzzle", *IMF Working Paper 74*.

Arthur B. W. (1994). *Increasing Returns and Path Dependence in the Economy*, Ann Arbor, MI: University of Michigan Press.

Bukh P. N., Marr B. and Mouritsen J. (2005). "A reporting perspective on intellectual capital", in: Marr B. (Ed.), *Perspectives on Intellectual Capital*, Elsevier Butterworth Heinemann, pp. 69-81.

Chen S. and Wang D. (2010). "High performance work systems and organizational innovative capabilities in the PRC: The mediating role of intellectual capital", in: *2010 Proceedings of PICMET*, p. 10.

Cheng M., Lin J., Hsiao T. and Lin T. W. (2008). "Censoring model for evaluating intellectual capital value drivers", *Journal of Intellectual Capital*, Vol. 9, No. 4, pp. 639-654.

Cheng M., Lin J., Hsiao T. and Lin T. W. (2010). "Invested resource, competitive intellectual capital, and corporate performance", *Journal of Intellectual Capital*, Vol. 11, No. 4, pp. 433-450.

Cobb C. W. and Douglas P. H. (1928). "A theory of production", *The American Economic Review*, Vol. 18, No. 1, pp. 139-165.

Croissant Y. and Millo G. (2008). "Panel data econometrics in R: The plm package", *Journal of Statistical Software*, Vol. 27, No. 2, pp. 1-51.

Drnevich P. and Shanley M. (2005a). "Multi-level issues for strategic management research: Further reflections", in: F. Dansereau, F. J. Yammarino, P. Drnevich & M. Shanley (Eds.), *Multi-Level Issues in Strategy and Methods: Research in Multi-Level Issues*, Vol. 4, Oxford: Elsevier Ldt., pp. 189-194.

Drnevich P. and Shanley M. (2005b). "Multi-level issues for strategic management research: Implications for creating value and competitive advantage", in: F. Dansereau, F. J. Yammarino, P. Drnevich and M. Shanley (Eds.), *Multi-Level Issues in Strategy and Methods: Research in Multi-Level Issues*, Vol. 4, Oxford: Elsevier Ldt., pp. 117-161.

Edvinsson L. and Lin C. Y. (2011). *National Intellectual Capital: A Comparison of 40 Countries*, New York, NY: Springer Science + Business Media, LLC.

Edvinsson L. and Malone M. S. (1997). *Intellectual Capital: The Proven Way to Establish Your Company's Real Value by Measuring Its Hidden Brainpower*, London: Piatkus.

Foss N. and Ishikawa I. (2007). "Peripheral vision: Towards a dynamic resource-based view: Insights from Austrian capital and entrepreneurship theory", *Organization Studies*, Vol. 28, No. 5, pp. 749-772.

Hall R. (1992). "The strategic analysis of intangible resources", *Strategic Management Journal*, Vol. 13, pp. 135-144.

Harlow H. and Imam S. (2006). "The effect of tacit knowledge management on innovation: Matching technology to strategies", in: *2006 Technology Management for the Global Future-PICMET 2006 Conference*, pp. 1236-1250.

Heathfield D. F. and Wibe S. (1987). *Introduction to Cost and Production Functions*, London: McMillan Education.

Hrishikesh V. D. (2008). "Production function and regression methods using R.", in: *Hands on Intermediate Econometrics Using R*, Hackensack: Publishing, World Scientific, pp. 1-76.

Hsu L. and Wang C. (2010). "Clarifying the effect of intellectual capital on performance: The mediating role of dynamic capability", *British Journal of Management*, Vol. 1, No. 2, pp. 1-27.

Ittner C. D. (2008). "Does measuring intangibles for management purposes improve performance? A review of the evidence", *Accounting and Business Research*, Vol. 38, No. 3, pp. 261-272.

Leiblein M. J. and Madsen T. L. (2007). "Resource stocks, innovation & persistent heterogeneity", in: *Academy of Management Proceedings*.

Leiblein M. J. and Madsen T. L. (2009). "Unbundling competitive heterogeneity: Incentive structures and capability influence on technological innovation", *Strategic Management Journal*, Vol. 30, pp. 711-735.

Lev B., Cañibano L. and Marr B. (2005). "An accounting perspective on intellectual capital", in: B. Marr (Ed.), *Perspectives on Intellectual Capital*, Chapter 3, Oxford: Elsevier, pp. 42-55.

Lockett A. and Thompson S. (2001). "The resource-based view and economics", *Journal of Management*, Vol. 27, No. 6, pp. 723-754.

Mackey A. and Barney J. B. (2005). "Developing multi-level theory in strategic management: The case of managerial talent and competitive advantage", in: F. Dansereau, F. J. Yammarino, P. Drnevich & M. Shanley (Eds.), *Multi-Level Issues in Strategy and Methods: Research in Multi-Level Issues*, Vol. 4, Oxford: Elsevier Ldt., pp. 163-175.

Mendenhall W. and Sincich T. (2011). *A Second Course in Statistics: Regression Analysis* (7th ed.), Boston: Pearson.

Nerlove M. (1965). *Estimation and Identification of Cobb-Douglas Production Functions*, Amsterdam: North-Holland Publishing Company.

Peteraf M. (2005). "A resource-based lens on value creation, competitive advantage, and multi-level issues in strategic management research", in: F. Dansereau, F. J. Yammarino, P. Drnevich & M. Shanley (Eds.), *Multi-Level Issues in Strategy and Methods: Research in Multi-Level Issues*, Vol. 4, Oxford: Elsevier, pp. 177-188.

Quinn J. B., Anderson P. and Finkelstein S. (1996). "Leveraging intellect", *Academy of Management*, Vol. 10, No. 3, pp. 7-27.

Reed K. K., Lubatkin M. and Srinivasan N. (2006). "Proposing and testing an intellectual capital-based view of the firm", *Journal of Management Studies*, Vol. 43, No. 4, pp. 0022-2380.

Roos J., Roos G., Dragonetti N. C. and Edvinsson L. (1997). *Intellectual Capital, Navigating the New Business Landscape*, Basingstoke: Macmillan.

Saint-Onge H. (1996). "Tacit knowledge the key to the strategic alignment of intellectual capital", *Strategy & Leadership*, pp. 10-15.

Stewart T. A. (1997). *Intellectual Capital: The New Wealth of Organizations*, London: Nicholas Brealey Publishing.

Tayles M., PikeR. H. and Sofian S. (2007). "Intellectual capital, management accounting practices and corporate performance: Perceptions of managers", *Accounting, Auditing & Accountability Journal*, Vol. 20, No. 4, pp. 522-548.

Teece D. J., Pisano G. and Shuen A. M. Y. (1997). "Dynamic capabilities and strategic management", *Strategic Management Journal*, Vol. 18, No. 7, pp. 509-533.

USPTO (2013). "United States National Patent Bureau", available online at: http://patft.uspto.gov/netahtml/PTO/search-adv.htm.

Wang J. (2008). "Investigating market value and intellectual capital for S&P 500", *Journal of Intellectual Capital*, Vol. 9, No. 4, pp. 546-563.

Wang W. and Chang C. (2005). "Intellectual capital and performance in causal models: Evidence from the information technology industry in Taiwan", *Journal of Intellectual Capital*, Vol. 6, No. 2, pp. 222-236.

World Bank (2013). "Methodologies: Growth rate", available online at: http://data.worldbank.org/about/data-overview/methodologies.

Yang S. and Kang H. (2008). "Is synergy always good? Clarifying the effect of innovation capital and customer capital on firm performance in two contexts", *Technovation*, Vol. 28, No. 10, pp. 667-678.

Zéghal D. and Maaloul A. (2010). "Analyzing value added as an indicator of intellectual capital and its consequences on company performance", *Journal of Intellectual Capital*, Vol. 11, No. 1, pp. 39-60.

Appendix 1 The Companies

ID	Company Name	Ticker	NAICS 2007 Industrial Sector	Industrial Area
1	ABBOTT LABORATORIES	ABT	Chemicals	Manufacturing
2	ALLERGAN INC	AGN	Chemicals	Manufacturing
3	AMGEN INCORPORATED	AMGN	Chemicals	Manufacturing
4	BRISTOL-MYERS SQUIBB COMPANY	BMY	Chemicals	Manufacturing
5	CABOT CORP	CBT	Chemicals	Manufacturing
6	CALGON CARBON CORPORATION	CCC	Chemicals	Manufacturing
7	CABOT MICROELECTRONICS CORP	CCMP	Chemicals	Manufacturing
8	CELGENE CORP	CELG	Chemicals	Manufacturing
9	CHEMTURA CORPORATION	CHMT	Chemicals	Manufacturing
10	CYTEC INDUSTRIES INC	CYT	Chemicals	Manufacturing
11	DU PONT (EI) DE NEMOURS	DD	Chemicals	Manufacturing
12	DOW CHEMICAL COMPANY (THE)	DOW	Chemicals	Manufacturing
13	FOREST LABORATORIES INC	FRX	Chemicals	Manufacturing
14	INTERNATIONAL FLAVORS & FRAGRANCES	IFF	Chemicals	Manufacturing
15	LIFE TECHNOLOGIES CORPORATION	LIFE	Chemicals	Manufacturing
16	MERCK & CO INC	MRK	Chemicals	Manufacturing
17	PFIZER INC	PFE	Chemicals	Manufacturing
18	PPG INDUSTRIES INC	PPG	Chemicals	Manufacturing
19	VALSPAR CORP	VAL	Chemicals	Manufacturing
20	WATSON PHARMACEUTICALS INC	WPI	Chemicals	Manufacturing
21	APPLE INC	AAPL	Computer and electronicproducts	Manufacturing
22	ARTHROCARE CORP	ARTC	Computer and electronicproducts	Manufacturing
23	ATMI INC	ATMI	Computer and electronicproducts	Manufacturing
24	CTS CORP	CTS	Computer and electronicproducts	Manufacturing
25	CYMER INC	CYMI	Computer and electronicproducts	Manufacturing
26	DIGI INTERNATIONAL INC	DGII	Computer and electronicproducts	Manufacturing
27	ELECTRONICS FOR IMAGING INC	EFII	Computer and electronicproducts	Manufacturing
28	EMC CORP	EMC	Computer and electronicproducts	Manufacturing
29	EMCORE CORP	EMKR	Computer and electronicproducts	Manufacturing
30	FARO TECHNOLOGIES INC	FARO	Computer and electronicproducts	Manufacturing
31	GREATBATCH INC	GB	Computer and electronicproducts	Manufacturing
32	ITT CORPORATION	ITT	Computer and electronicproducts	Manufacturing
33	JUNIPER NETWORKS INC	JNPR	Computer and electronicproducts	Manufacturing
34	MERGE HEALTHCARE INCORPORATED	MRGE	Computer and electronicproducts	Manufacturing
35	MOTOROLA SOLUTIONS INC	MSI	Computer and electronicproducts	Manufacturing
36	MAXWELL TECHNOLOGIES INC	MXWL	Computer and electronicproducts	Manufacturing
37	NVIDIA CORP	NVDA	Computer and electronicproducts	Manufacturing
38	OYO GEOSPACE CORP	OYOG	Computer and electronicproducts	Manufacturing
39	PLX TECHNOLOGY INC	PLXT	Computer and electronicproducts	Manufacturing
40	QUALITY SYSTEMS INC	QSII	Computer and electronicproducts	Manufacturing
41	RAYTHEON COMPANY	RTN	Computer and electronicproducts	Manufacturing
42	SILICON LABORATORIES INC	SLAB	Computer and electronicproducts	Manufacturing
43	STANDARD MICROSYSTEMS CORP	SMSC	Computer and electronicproducts	Manufacturing
44	THORATEC CORP	THOR	Computer and electronicproducts	Manufacturing
45	TEKELEC	TKLC	Computer and electronicproducts	Manufacturing

(Appendix 1 to be coninued)

(Appendix 1 coninued)

46	MERIDIAN BIOSCIENCE INC	VIVO	Computer and electronicproducts	Manufacturing
47	BROOKS AUTOMATION INC	BRKS	Machinery	Manufacturing
48	CATERPILLAR INC	CAT	Machinery	Manufacturing
49	CUMMINS INC	CMI	Machinery	Manufacturing
50	HARSCO CORP	HSC	Machinery	Manufacturing
51	RUDOLPH TECHNOLOGIES INC	RTEC	Machinery	Manufacturing
52	XEROX CORP	XRX	Machinery	Manufacturing
53	CROSS AT CO	ATX	Miscellaneousmanufacturing	Manufacturing
54	BAXTER INTERNATIONAL INC	BAX	Miscellaneousmanufacturing	Manufacturing
55	HASBRO INC	HAS	Miscellaneousmanufacturing	Manufacturing
56	JOHNSON OUTDOORS INC	JOUT	Miscellaneousmanufacturing	Manufacturing
57	QUIDEL CORP	QDEL	Miscellaneousmanufacturing	Manufacturing
58	RTI BIOLOGICS INC	RTIX	Miscellaneousmanufacturing	Manufacturing
59	SHUFFLE MASTER INC	SHFL	Miscellaneousmanufacturing	Manufacturing
60	WRIGHT MEDICAL GROUP INC	WMGI	Miscellaneousmanufacturing	Manufacturing
61	ASIAINFO-LINKAGE INC	ASIA	Professional scientific and technical services	Non-manufacturing
62	CEPHALON INC	CEPH	Professional scientific and technical services	Non-manufacturing
63	DIGITAL RIVER INC	DRIV	Professional scientific and technical services	Non-manufacturing
64	INTERNATIONAL BUSINESS MACHINES CORP	IBM	Professional scientific and technical services	Non-manufacturing
65	UNISYS CORP	UIS	Professional scientific and technical services	Non-manufacturing
66	ANSYS INC	ANSS	Publishing	Non-manufacturing
67	ACTUATE CORP	BIRT	Publishing	Non-manufacturing
68	3D SYSTEMS CORPORATION	DDD	Publishing	Non-manufacturing
69	ELECTRONIC ARTS INC	ERTS	Publishing	Non-manufacturing
70	OPNET TECHNOLOGIES INC	OPNT	Publishing	Non-manufacturing
71	PROGRESS SOFTWARE CORP	PRGS	Publishing	Non-manufacturing
72	RENAISSANCE LEARNING INC	RLRN	Publishing	Non-manufacturing
73	ROVI CORP	ROVI	Publishing	Non-manufacturing
74	SMITH MICRO SOFTWARE INC	SMSI	Publishing	Non-manufacturing

Appendix 2 Economic Quantities

In a restricted Cobb-Douglas function, the elasticity of scale is equal to the sum of the coefficients (Heathfield & Wibe, 1987, p. 84). The elasticity of scale ε is the ratio of the proportionate increase in output ($\Delta q_i/q_i$) to the proportionate increase in inputs, $\Delta v_i/v_i$, so that the elasticity of scale is $\varepsilon_i = (\Delta q_i/q_i)/(\Delta v_i/v_i)$. The elasticity of scale for n factors of production

$$\varepsilon = \sum_{i=1}^{n} f_i (v_i/q) \tag{4}$$

Where $f_i = (\partial q/\partial v_i)$ can be constant, i.e. $\varepsilon = 1$, specifies that the doubling of all inputs leads to a doubling of output. If $\varepsilon < 1$, then doubling all inputs will lead to a less than doubling of the output, a case which is called decreasing returns to scale. If $\varepsilon > 1$, then doubling all inputs will lead to a more than doubling of the output and increasing returns to scale are obtained (Heathfield & Wibe 1987, pp. 55-56).

The elasticity of cost E_c is the ratio of relative increase in cost to relative increase in output, $E_c = (\Delta C_i/C_i)/(\Delta q_i/q_i)$, being reciprocal to the elasticity of scale $E_c=1/\varepsilon$. Firms with increasing returns to scale exhibit falling average costs, firms with constant returns to scale exhibit constant costs, whilst firms with decreasing returns to scale exhibit rising production costs (Heathfield & Wibe, 1987, pp. 56-58).

The unrestricted Cobb-Douglas production form has the same individual elasticities and returns to scale as the restricted Cobb-Douglas production function form:

$\varepsilon_{HC} = \beta_{HC} + \gamma_{HC*CC}\ln(CC) + \gamma_{HC*SC}\ln(SC) + \gamma_{HC*R\&D}\ln(R\&D) + \gamma_{HC*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{HC*PATENTS}\ln(PATENTS) + \gamma_{HC*LABOR}\ln(LABOR)$,

$\varepsilon_{CC} = \beta_{CC} + \gamma_{CC*HC}\ln(HC) + \gamma_{CC*SC}\ln(SC) + \gamma_{CC*R\&D}\ln(R\&D) + \gamma_{CC*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{CC*PATENTS}\ln(PATENTS) + \gamma_{CC*LABOR}\ln(LABOR)$,

$\varepsilon_{SC} = \beta_{SC} + \gamma_{SC*HC}\ln(HC) + \gamma_{SC*CC}\ln(CC) + \gamma_{SC*R\&D}\ln(R\&D) + \gamma_{SC*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{SC*PATENTS}\ln(PATENTS) + \gamma_{SC*LABOR}\ln(LABOR)$,

$\varepsilon_{LAGGED\ R\&D} = \beta_{LAGGED\ R\&D} + \gamma_{LAGGED\ R\&D*HC}\ln(HC) + \gamma_{LAGGED\ R\&D*CC}\ln(CC) + \gamma_{LAGGED\ R\&D*SC}\ln(SC) + \gamma_{LAGGED\ R\&D*R\&D}\ln(R\&D) + \gamma_{LAGGED\ R\&D*PATENTS}\ln(PATENTS) + \gamma_{LAGGED\ R\&D*LABOR}\ln(LABOR)$,

$\varepsilon_{R\&D} = \beta_{R\&D} + \gamma_{R\&D*HC}\ln(HC) + \gamma_{R\&D*CC}\ln(CC) + \gamma_{R\&D*SC}\ln(SC) + \gamma_{R\&D*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{R\&D*PATENTS}\ln(PATENTS) + \gamma_{R\&D*LABOR}\ln(LABOR)$,

$\varepsilon_{PATENTS} = \beta_{PATENTS} + \gamma_{PATENTS*HC}\ln(HC) + \gamma_{PATENTS*CC}\ln(CC) + \gamma_{PATENTS*SC}\ln(SC) + \gamma_{PATENTS*R\&D}\ln(R\&D) + \gamma_{PATENTS*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{PATENTS*LABOR}\ln(LABOR)$ and

$\varepsilon_{LABOR} = \beta_{LABOR} + \gamma_{LABOR*HC}\ln(HC) + \gamma_{LABOR*CC}\ln(CC) + \gamma_{LABOR*SC}\ln(SC) + \gamma_{LABOR*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{LABOR*R\&D}\ln(R\&D) + \gamma_{LABOR*PATENTS}\ln(PATENTS)$.

The output elasticities of the respective inputs of the translog model are:

$\varepsilon_{HC} = (\partial \ln Y/\partial \ln HC) = \beta_{HC} + \gamma_{HC*HC}\ln(HC) + \gamma_{HC*CC}\ln(CC) + \gamma_{HC*SC}\ln(SC) + \gamma_{HC*R\&D}\ln(R\&D) + \gamma_{HC*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{HC*PATENTS}\ln(PATENTS)\gamma_{HC*LABOR}\ln(LABOR)$,

$\varepsilon_{CC} = (\partial \ln Y/\partial \ln CC) = \beta_{CC} + \gamma_{CC*HC}\ln(HC) + \gamma_{CC*CC}\ln(CC) + \gamma_{CC*SC}\ln(SC) + \gamma_{CC*R\&D}\ln(R\&D) + \gamma_{CC*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{CC*PATENTS}\ln(PATENTS) + \gamma_{CC*LABOR}\ln(LABOR)$,

$\varepsilon_{SC} = (\partial \ln Y/\partial \ln SC) = \beta_{SC} + \gamma_{SC*HC}\ln(HC) + \gamma_{SC*CC}\ln(CC) + \gamma_{SC*SC}\ln(SC) + \gamma_{SC*R\&D}\ln(R\&D) + \gamma_{SC*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{SC*PATENTS}\ln(PATENTS) + \gamma_{SC*LABOR}\ln(LABOR)$,

$\varepsilon_{LAGGED\ R\&D} = (\partial \ln Y/\partial \ln LAGGED\ R\&D) = \beta_{LAGGED\ R\&D} + \gamma_{LAGGED\ R\&D*HC}\ln(HC) + \gamma_{LAGGED\ R\&D*CC}\ln(CC) + \gamma_{LAGGED\ R\&D*SC}\ln(SC) + \gamma_{LAGGED\ R\&D*R\&D}\ln(R\&D) + \gamma_{LAGGED\ R\&D*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{LAGGED\ R\&D*PATENTS}\ln(PATENTS) + \gamma_{LAGGED\ R\&D*LABOR}\ln(LABOR)$,

$\varepsilon_{R\&D} = (\partial \ln Y/\partial \ln R\&D) = \beta_{R\&D} + \gamma_{R\&D*HC}\ln(HC) + \gamma_{R\&D*CC}\ln(CC) + \gamma_{R\&D*SC}\ln(SC) + \gamma_{R\&D*R\&D}\ln(R\&D) + \gamma_{R\&D*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{R\&D*PATENTS}\ln(PATENTS) + \gamma_{R\&D*LABOR}\ln(LABOR)$,

$\varepsilon_{PATENTS} = (\partial \ln Y/\partial \ln PATENTS) = \beta_{PATENTS} + \gamma_{PATENTS*HC}\ln(HC) + \gamma_{PATENTS*CC}\ln(CC) + \gamma_{PATENTS*SC}\ln(SC) + \gamma_{PATENTS*R\&D}\ln(R\&D) + \gamma_{PATENTS*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{PATENTS*PATENTS}\ln(PATENTS) + \gamma_{PATENTS*LABOR}\ln(LABOR)$ and

$\varepsilon_{LABOR} = (\partial \ln Y/\partial \ln L) = \beta_{LABOR} + \gamma_{LABOR*HC}\ln(HC) + \gamma_{LABOR*CC}\ln(CC) + \gamma_{LABOR*SC}\ln(SC) + \gamma_{LABOR*R\&D}\ln(R\&D) + \gamma_{LABOR*LAGGED\ R\&D}\ln(LAGGED\ R\&D) + \gamma_{LABOR*PATENTS}\ln(PATENTS) + \gamma_{LABOR*LABOR}\ln(LABOR)$.

In the translog function, the elasticity depends on the levels of the inputs used in production. The returns to scale can be found by adding up the individual elasticities:

$$
\begin{aligned}
\varepsilon = {} & (\beta_{HC} + \beta_{CC} + \beta_{SC} + \beta_{LAGGED\ R\&D} + \beta_{R\&D} + \beta_{PATENTS} + \beta_{LABOR)} \\
& + (\gamma_{HC*HC} + \gamma_{CC*HC} + \gamma_{SC*HC} + \gamma_{LAGGED\ R\&D*HC} + \gamma_{R\&D*HC} + \gamma_{PATENTS*HC} + \gamma_{LABOR*HC})^{\ln HC} \\
& + (\gamma_{HC*CC} + \gamma_{CC*CC} + \gamma_{SC*CC} + \gamma_{LAGGED\ R\&D*CC} + \gamma_{R\&D*CC} + \gamma_{PATENTS*CC} + \gamma_{LABOR*CC})^{\ln CC} \\
& + (\gamma_{HC*SC} + \gamma_{CC*SC} + \gamma_{SC*SC} + \gamma_{LAGGED\ R\&D*SC} + \gamma_{R\&D*SC} + \gamma_{PATENTS*SC} + \gamma_{LABOR*SC})^{\ln SC} \\
& + (\gamma_{HC*LAGGED\ R\&D} + \gamma_{CC*LAGGED\ R\&D} + \gamma_{SC*LAGGED\ R\&D} + \gamma_{R\&D*LAGGED\ R\&D} \\
& + \gamma_{LAGGED\ R\&D*LAGGEDR\&D} + \gamma_{PATENTS*LAGGED\ R\&D} + \gamma_{LABOR*LAGGED\ R\&D})^{\ln LAGGED\ R\&D} \\
& + (\gamma_{HC*R\&D} + \gamma_{CC*R\&D} + \gamma_{SC*R\&D} + \gamma_{LAGGED\ R\&D*R\&D} + \gamma_{R\&D*R\&D} + \gamma_{PATENTS*R\&D} \\
& + \gamma_{LABOR*R\&D})^{\ln R\&D} \\
& + (\gamma_{PATENTS*HC} + \gamma_{PATENTS*CC} + \gamma_{PATENTS*SC} + \gamma_{PATENTS*R\&D} + \gamma_{PATENTS*LAGGED\ R\&D} \\
& + \gamma_{PATENTS*LABOR} + \gamma_{PATENTS*PATENTS})^{\ln PATENTS} \\
& + (\gamma_{HC*LABOR} + \gamma_{CC*LABOR} + \gamma_{SC*LABOR} + \gamma_{R\&D*LABOR} + \gamma_{LAGGED\ R\&D*LABOR} + \gamma_{PATENTS*LABOR} \\
& + \gamma_{LABOR*LABOR})^{\ln LABOR}.
\end{aligned}
$$

The elasticity of total cost with respect to output is given by

$$[d(\ln(c))/d(\ln(y))] = (y/c)(d(c)/d(y)) = MC/AC \qquad (5)$$

Where the marginal cost MC = d(c)/d(y) and average cost AC = c/y. This also shows that the reciprocal of the scale elasticity is the elasticity of total cost with respect to output, or percent change in total cost as output increases with one percent (Hrishikesh, 2008, p. 32).

The translog function reduces to the Cobb-Douglas functional form when the following conditions are satisfied:

- $\beta_{HC} + \beta_{CC} + \beta_{SC} + \beta_{R\&D} + \beta_{LAGGED\ R\&D} + \beta_{PATENTS} + \beta_{LABOR} = 1$
- $(\gamma_{HC*HC} + \gamma_{CC*HC} + \gamma_{SC*HC} + \gamma_{R\&D*HC} + \gamma_{LAGGED\ R\&D*HC} + \gamma_{PATENTS*HC} + \gamma_{LABOR*HC} = 0$
- $\gamma_{HC*CC} + \gamma_{CC*CC} + \gamma_{SC*CC} + \gamma_{R\&D*CC} + \gamma_{LAGGED\ R\&D*CC} + \gamma_{PATENTS*CC} + \gamma_{LABOR*CC} = 0$
- $\gamma_{HC*SC} + \gamma_{CC*SC} + \gamma_{SC*SC} + \gamma_{R\&D*SC} + \gamma_{LAGGED\ R\&D*SC} + \gamma_{PATENTS*SC} + \gamma_{LABOR*SC} = 0$
- $\gamma_{HC*R\&D} + \gamma_{CC*R\&D} + \gamma_{SC*R\&D} + \gamma_{LAGGED\ R\&D*R\&D} + \gamma_{PATENTS*R\&D} + \gamma_{LABOR*R\&D} = 0$
- $\gamma_{HC*LAGGED\ R\&D} + \gamma_{CC*LAGGED\ R\&D} + \gamma_{SC*LAGGED\ R\&D} + \gamma_{R\&D*LAGGED\ R\&D} + \gamma_{PATENTS*LAGGED\ R\&D} + \gamma_{LABOR*LAGGED\ R\&D} = 0$
- $\gamma_{LABOR*HC} + \gamma_{CC*LABOR} + \gamma_{SC*LABOR} + \gamma_{LAGGED\ R\&D*LABOR} + \gamma_{R\&D*LABOR} + \gamma_{PATENTS*LABOR} = 0$.

Appendix 3 Varioustests

In order to determine the statistical reliability of the unrestricted Cobb-Douglas production function (3) over the restricted Cobb-Douglas production shape (2) and the transcendental logarithmic function (4), nested F-tests were performed with the unrestricted (3) and translog (4) functions as full models. The results are presented in Table Appendix 3A.

Appendix 3A Nested F-tests

Models	F	df	Pr(>F)
Unrestricted Cobb-Douglas, Restricted Cobb-Douglas	7.323	df(1) = 21; df(2) = 485	< 2.2^{e-16}
Translog Cobb-Douglas, Unrestricted Cobb-Douglas	8.570	df(1) = 7; df(2) = 478	6.533^{e-10}
Translog Cobb-Douglas, Restricted Cobb-Douglas	8.235	df(1) = 28; df(2) = 478	< 2.2^{e-16}

The p-values of all the tests are lower than 0.05 and the null hypotheses of no additional explanation power of the full models can hence be rejected. The full models (indicated to the left) are better choices than the restricted models (indicated to the right). The last test shows that the translog function is more suitable than the unrestricted Cobb-Douglas production function.

The superiority of the translog production function was though rejected by additional tests which are presented in Table Appendix 3Band which support the hypothesis that the interactions of the translog model are not significantly different from zero.

Appendix 3B Interaction Hypothesis Tests

Model	F	Res. df	df	Pr(> F)
Unrestricted Cobb-Douglas H_0: β_8: $\beta_{28} = 0$	8.250	df(1) = 486; df(2) = 485	1	0.004254 **
Translog Cobb-Douglas H_0: β_8:$\beta_{35} = 0$	0.951	df(1) = 479; df(2) = 478	1	0.33

P-values smaller than 0.05 in the unrestricted Cobb-Douglas model lead to the conclusion that the null hypothesis of a zero difference between the interaction parameters can be rejected in favor of its alternative, a significant difference between at least two of the interacting parameters. The second test indicates that this is not the case for the translog model, since the p-value is greater than the confidence limit of 0.05. Based on these results, it can be concluded that the applied translog function is not better suited than the unrestricted Cobb-Douglas production form. The analysis proceeds thus with the unrestricted Cobb-Douglas production function.

Table Appendix 3C presents the results of diagnostictests applied on the selected unrestricted Cobb-Douglas model. The tests are performed in agreement with the recommendations made in the statistical package's documentation (Croissant & Millo, 2008). The Breusch-Pagan Lagrange Multiplier test for random effects panel models indicates the presence of random effects in the plm model when compared to its pooling version (the equivalent to ordinary least squares). The null hypothesis of no panel effect (i.e., of variances across entities being zero)was hence rejected in favor of a significant difference across the units of the test.In the second test, the presence of time effects is stated. After evaluating all random transformations with random effects, the Nerlove transformation with time effects was chosen due to it superiority of variance explanation. The Bera, Sosa-Escuerdo and Yoon locally robust test is a joint test which has the power of testing serial correlation within the presence of random effects. Since the p-value is smaller than 0.05, no serial correlation is indicated in the model.

Appendix 3C Diagnostic Tests

Test	χ^2/z-value	df	P-value
Breusch Pagan LM Test – Random effects	213.82	1	$< 2.22^{e-16}$
Breusch Pagan LM Test – Time effects	29.65	1	5.188^{e-08}
Bera, Sosa-Escuerdo and Yoon Locally Robust Test	111.91	1	$< 2.22^{e-16}$
Baltagi and Li AR-RE Joint Test	345.24	2	$< 2.22^{e-16}$
Hausman Test	3.20	32	1.000
Pesaran Cross-Sectional Dependence Test	(z) -0.19	---	0.8496

The Baltagi and Li AR-RE test is a joint test for random effects and serial correlation under normality and homoscedasticity of the idiosyncratic errors. Likewise, this test indicates that there is no autocorrelation present in the model. The adequacy of random effects over fixed effects was tested in the Hausman test to analyze if the unique errors u_i are correlated with the regressors. The null hypothesis postulates that they are not correlated and since the p-value is not significant, random effects should be used. The F-tests performed between the fitted within (i.e., fixed effects model) and pooled models have been purposely omitted, since the presence of random effects was stated in the Hausman test and they therefore have no further relevance. The documentation of the plm package specifies that the random estimators are the most advanced ones in the plm package and are preferred when tests indicate their suitability. The Pesaran cross-sectional dependence test indicates a p-value greater than 0.05 in the model. Hence, the null hypotheses of no correlation of the residuals across the entities could not be rejected and it can therefore be concluded that cross-sectional dependence does not cause a problem of contemporaneous correlation. The p-value of the plm model is smaller than 2.22^{e-16}, indicating overall reliability.