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Impact of Technological Innovation Capabilities on the Market Value of Firms

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Abstract. In the era of globalisation and with the advent of knowledge economies, organisational innovation has assumed a critical role in enhancing economic performance of firms. Proponents of the *Resource Based View* of the firm and its more recent extensions such as the *Knowledge Based View* and *Dynamic Capabilities Theory* have suggested that generation, diffusion and application of organisational knowledge could be the source of sustained competitive advantage and superior performance of firms. While there is near unanimity in accepting the vital role of innovation in a firm's performance, consensus on what constitutes organisational innovation and how to measure it has proven to be elusive so far. Most previous research in this area has conceptualised innovation through one or more dimensions of a firm's innovative capability using R&D of a firm only. The measurement of the construct has thus reflected this narrow conceptualisation with a single measure of R&D expenditure being the most often used proxy. This study utilises a broader definition of organisational innovation capabilities that includes the generation, dissemination and strength of innovative activity in a firm. The unique features of this study is that it uses multiple indicators of a firm's innovation profile along with lagged measures of market value using fixed effects panel data analysis.

Keywords: Innovation; R&D; firm value; panel data.

1. Innovation and Innovative Capability

Knowledge and the innovative capability of firms driven by technology are considered key factors in firm performance (Isobe *et al.*, 2008; Ma and Liao, 2006; Sher and Yang, 2005; Weikl and Grotz, 1999). Proponents of the *Resource Based Theory* (RBV) of the firm have supported this view by arguing that innovation, as a source of organisational "knowledge", could be a critical factor in attaining a sustainable competitive advantage for the firm (Barney, 1991). This view has been crafted into a framework of *Dynamic Capabilities* (DC) by researchers such as Teece *et al.* (1997). More recently, the *Knowledge Based View* (KBV) has emerged as a novel, if not radically new, perspective to examine the nexus between innovation and firm performance (Gopalakrishnan *et al.*, 1999). Chetty and Campbell-Hunt (2003) and Davenport *et al.* (2003) argued that the technology-driven strategy of firms helps them leverage their strengths toward obtaining international significance. Other interpretations of the important role of innovation in determining a firm's destiny include innovation as a barrier for entry and exit of competitors (Porter, 1983), as an instrument in increasing the market value of the firm (Toivanen *et al.*, 2002), as a strategic rent-generating asset (Teece *et al.*, 1997) and as a tool for organisational change (Birkinshaw *et al.*, 2002).

While there is near unanimity in accepting the vital role of technology-based innovation in a firm's performance and profitability, there is very little discussion or agreement on the conceptualisation and measurement of such an innovation and its relationship with different dimensions of corporate performance. We argue that a broader conceptualisation of what constitutes technological innovation and an accurate measurement of factors that are central to various aspects of technological innovation is critical to any extended study of technology and its applications. Thus, the purpose of this research is two-fold.

First, given the paucity of research that captures the multiple manifestations of technological innovation, this study intends to create a technological innovation capability profile of a firm that includes dimensions such as generation, dissemination and strength of a firm's innovation driven by its technological prowess. Second, it attempts to examine the role of innovation capability in predicting the market value of US-based firms.

2. Literature Review

2.1. *Conceptualisation and measurement of innovation*

Innovation has been defined as an "internally generated or (externally) purchased device, system, policy, program, process, product or service that is new to the adopting organisation" (Damanpour, 1992). Thompson (1965) defined innovation as the *generation* of new ideas, processes and products or services. But according to Feeny and Rogers (2003), innovation is the *application* of new ideas to the products and processes of a firm's activities, and according to Amabile *et al.* (1996), it is the successful *implementation* of creative ideas within an organisation. As can be seen there is a fair amount of debate on what actually constitutes organisational innovation. We argue that a comprehensive definition of innovation should include all the above dimensions.

The RBV (Barney, 1991; Wernerfelt, 1984) has largely driven academic research in this area which proposes that the firm is a collection of capabilities and that organisation's ability to exploit these capabilities in order to achieve competitive success. This theory also posits that the more valuable and inimitable these capabilities are, the more sustainable its competitive advantage is. The impact of organisational innovation and technology on competitive dynamics of a firm has also been highlighted in the works of Schumpeter (1934), Utterback and Abernathy (1975), Lipman and Rumelt (1982) and Teece (1982), to name a few. Although the idea of exploiting firm capabilities in order to achieve extraordinary results is not entirely new, the resource-based view has been instrumental in shaping the academic and practitioner focus on the "intangible" resources of the firm.

This focus on the intangible resources has also given rise to a "knowledge-based view" of the firm (Grant, 1996). This view provides a new perspective on not just the performance of the firm but its very existence — for the creation, transfer and application of knowledge (Demsetz, 1991; Grant, 1996). Thus, researchers in this area have viewed the innovation of a firm as a manifestation of firm-specific knowledge that is created and/or transferred in order to attain a competitive advantage and earn above average returns.

Thus, it is clear that although previous research in this area has conceptualised innovation of a firm through multiple dimensions of a firm's innovative capability, the measurement of organisational innovation has not reflected this. Most empirical studies have relied upon a single indicator such as R&D expenditure of a firm or number of patents only (Archibugi and Pianta, 1996). These measures, although useful indicators of a firm's innovation-driven output, are not an accurate reflection of its innovative capability. Moreover, patent counts do not reflect small and medium-sized enterprises adequately since many small firms do not patent their innovations for various reasons (Romijn and Albaladejo, 2002). A few researchers have attempted a composite index of innovation based on a factor analysis of several innovation variables (Hollenstein, 1996). This index included "input-oriented", "output-oriented" and "market-oriented" measures of innovation. Romijn and Albaladejo (2002) constructed an innovation index based on a survey of the "extent" and "significance" of a firm's innovative outputs (p. 1057). They found that the index was able to predict a firm's export orientation more than the single item measures such as patent counts.

2.2. *Performance implications of innovation*

Most studies linking innovation to firm performance can be categorised as those that use

(a) "Type" of innovation, such as administrative, technological, product or process-based, and
(b) "Extent" of innovation in an organisation, such as radical vs gradual innovation, extent of investment in R&D to generate innovative activity.

Damanpour *et al.* (1989) found a positive relationship between adoption of administrative and technical innovations over time and organisational performance. Ettlie (1983) and Kimberly and Evanisko (1980) are among other studies in this regard. Yamin *et al.* (2003) computed what they called an "innovation index" of a firm using administrative, technical and product innovation dimensions. While the idea of incorporating multiple dimensions is certainly meritorious, the study fails to incorporate the diffusion and management dimensions of innovation.

Feeny and Rogers (2003) studied the impact of innovation on firm performance using a sample of large Australian firms. Toivanen *et al.* (2002) studied the impact of firm innovation, as measured by its R&D spending, on the market value of the firm. They found that R&D positively impacts market value of a firm.

A few studies have focused on the impact of firm innovation or innovative capabilities on international performance of firms. The empirical studies on European firms by Roper and Love (2002), and on Chinese firms by Guan and Ma (2003) are a few examples. The latter study used a variety of innovative capability dimensions spanning the functional domain of firms such as R&D, marketing, resource allocation and strategic planning to predict the export behavior of a firm. They found evidence to support their claim that a collection of innovation dimensions including R&D promotes the international competitiveness of the firm.

Based on the previous research as discussed above and summarised in Table 1, the following conclusions can be drawn:

(1) Innovative capabilities of firms are important predictors of firm performance.
(2) Most studies use a narrow definition of innovation while it remains a multidimensional construct.
(3) Very few studies have examined the impact of innovation on market value of firms (almost none involving US firms).
(4) Very few studies used panel data methodology. Most of previous studies either used OLS or pooled OLS.

This paper addresses the above issues using a sample of 64 firms over a nine-year period by examining the relationship between a variety of innovation dimensions including generation, dissemination and strength of innovation that constitutes a firm's "innovation capability profile", and market value of firms.

We define innovation generation as the capacity of a firm to generate knowledge through investments in R&D, filing of patents, trademarks and copyrights and so on. We measure this by the number of patents filed by a firm with the United States Patent and Trademark Office (USPTO) in a given year.

We define innovation dissemination as the capacity of a firm to disseminate the knowledge it has generated for other applications or to generate further knowledge for the firm. A firm's capacity for knowledge dissemination can also be reflected in the way its patents are cited by other firms in the industry. Therefore we operationalise this by using an index that measures the impact and citation frequency of a firm's patents and resultant knowledge.

Finally, we argue that a firm's innovative capability lies not just in the number of patents it generates but also in the quality of such patents. By quality, we mean the strength of a firm's knowledge which can be measured by the quality-weighted portfolio size.

Please refer to Table 2 for specific operationalisation of each of the above.

The following hypotheses will be empirically verified:

(H1) *A firm's capacity for innovation generation is positively associated with its market value.*
(H2) *A firm's capacity for innovation dissemination is positively related to its market value.*
(H3) *A firm's strength of innovation is positively related to its market value.*

3. Research Methodology

3.1. *Sample*

An original cross-sectional national sample of 200 multinational firms from four sectors (biotechnology, chemicals, electronics and semiconductor) was selected for the study. The sample period is 1992−2000. The sample was randomly drawn from a list of manufacturing firms from the CHI Research™ (CHI) database containing patent information. These firms were then matched with the Compustat−Research Insight database that contained market value data. After eliminating firms with incomplete data on market value and other innovation related information, a total of 64 firms remained in the sample.

3.2. *Data and variables*

Data for dependent variable (market value) were obtained from the Research Insight® database. Data for the independent variables of Innovation capability profile were obtained from the patent database called TECH−LINE®, maintained by CHI. The use of patents and patent citations to measure innovation and knowledge of a firm has precedent in the studies by Narin *et al.* (1987), Jaffe *et al.* (2000) and Fung and Chow (2002). Table 2 explains the variables and their operationalisation.

3.3. *Empirical model*

In the econometrics literature, cross-sectional time-series models are called panel data. Panel data facilitates regression analysis in terms of spatial and temporal dimensions. The spatial dimension relates to a group of cross-sectional data (in our case the individual firms). On the other hand, the temporal dimension refers to periodic observations of a set of variables over a particular time period. In this study, time series of the observations are at individual firm level rather than aggregate level. In a pooled observation situation, estimating the OLS would yield a biased estimate.

For the panel data analysis, the data set consists of $i = 1, \ldots, N$ cross-sections (number of firms), and several points of time series for each firm $t = 1, \ldots, T(i)$, or a cross-section of N time series each of length $T(i)$. To break down the effect of R&D together with innovation generation, innovation dissemination and innovation strength, the following linear models are estimated:

(i) Ordinary Least Squares (OLS).

$$\mathrm{FV}_{it} = \lambda_i + \beta'\mathrm{G}_{it} + \alpha'\mathrm{D}_{it} + \gamma'\mathrm{S}_{it} + \phi'\mathrm{X}_{it} + \mu_{it} \quad (1)$$

where FV_{it} is the firm value in firm $i = 1, \ldots, N$, year $t = 1, \ldots, T(i)$.

Table 1. Innovation — conceptualisation and measurement.

Study	Conceptualisation of innovation	Measurement	Criterion variable
Morone and Testa (2008)	Process innovation Product innovation Organisational changes Marketing innovation		Turnover growth of 2600 Italian SMEs
Isobe *et al.* (2008)	Technological capabilities	Refinement capabilities Reconfiguration capabilities	Firm performance of 302 Japanese SMEs
Ma and Liao (2006)	Innovative capability	(1) Technological capability (2) Managerial capability (3) Resource exploiting capability	International competitiveness of 213 Chinese firms in Beijing
Flor and Oltra (2005)	Technological innovation on their export performance	Investment in internal non-R&D innovative activities (engineering design and pre-production), investment in R&D, investment in external acquisition of technology	Export performance of 88 Spanish firms
Hult *et al.* (2004)	Capacity of firms to introduce new product, process or idea in the organisation	Number of new ideas recognized and adapted in the organisation	(1) Business performance (2) Profitability (3) Sales growth and (4) Market share growth
Ozcelik and Taymaz (2004)	Technological capabilities to enhance product and process introductions	Rate of product and process innovations in firms (based on survey)	Export performance of Turkish manufacturers
Hsueh and Tu (2004)	Entrepreneurial spirit	Factor analysis leading to (1) innovative atmosphere (2) ability to innovate (3) management system innovation and (4) innovative actions	(1) Sales growth (2) Growth in operating profit
Acs *et al.* (2002)	Knowledge generated in firm including product, process and “disruptive” types	(1) Number of patents granted (2) Employment in R&D laboratories (3) University R&D expenses (4) Private sector R&D expenses	Innovation activity
Romijn and Albaladejo (2002)	Degree of novelty in product introductions	Product innovation index (5 item scale based on survey)	Export orientation of firm

Table 1. (*Continued*)

Study	Conceptualisation of innovation	Measurement	Criterion variable
Soutaris (2002)	Portfolio of a firm's (1) Technological competencies (2) Human resource competencies (3) Organisational competencies (4) Market Competencies	Multiple indicators using OECD (1992) study (1) Number of incrementally innovative products introduced in last 3 yrs (2) Number of radically innovative products introduced in last 3 yrs (3) Number of innovative manufacturing processes introduced in last 3 yrs (4) % of current sales due to radically innovative products innovative products (5) % of current sales due to incrementally (6) R&D expenditure (7) Number of patents	Rate of technological innovation
Yamin *et al.* (1999)		Aggregate "index" consisting of (1) Administrative (2) Technical and (3) Product dimensions	Firm performance
Hollenstein (1996)	Complex activity permeating all stages a firm's value chain	Aggregate indicator based on factor analysis of (1) product (technology and market dimensions) (2) process (input and output stages)	N/A
Leonard-Barton (1992)	Core competencies of a firm based on (1) Technical systems (2) People's skills and knowledge (3) Managerial systems and (4) Values and norms	N/A	New product development

Table 2. Operationalisation of variables.

Independent Variables
INNOVATION GENERATION: Number of patents (PAT)
The number of patents identifies technologies receiving increasing emphasis and those in which innovation is slackening off. It also identifies companies increasing their technological development, and those whose R&D has been played out.
INNOVATION DISSEMINATION: Current Impact Index (CII)
The number of times a company's patents in the previous five years is cited in the current year, relative to all patents in the U.S. patent system. Indicates patent portfolio quality. A value of 1.0 represents average citation frequency; a value of 2.0 represents twice the average citation frequency; and 0.25 represents 25% of the average citation frequency. In a Tech-Line company report, you can identify the technologies in which companies produce their best work. The CII has been found to be predictive of a company's stock market performance.
INNOVATION STRENGTH: Technology strength (TECH)
Quality-weighted portfolio size, defined as the number of patents multiplied by current impact index. Using Technology Strength you may find that although one company has more patents, a second may be technologically more powerful because its patents are of a better quality.
Dependent Variable
Market Value is defined as the value of a firm's equity plus debt (Toivanen *et al.*, 2002). We used the proxy Market to Book Value of a firm (MKBK) from Compustat−Research Insight to measure the market value.

G_{it} is the vector of generation of innovation variables.
D_{it} is the vector of dissemination of innovation variables.
S_{it} is the vector of strength of innovation variables.
X_{it} is the R&D expenditure.
λ_i is the overall constant term, which is the same for all firms.
μ_{it} is independently and identically distributed among firms and years.

(ii) Fixed Effects.

$$\mathrm{FV}_{it} = \eta_1\delta_{1it} + \eta_2\delta_{2it} + \cdots + \beta'\mathrm{G}_{it} + \alpha'\mathrm{D}_{it} + \gamma'\mathrm{S}_{it} + \phi'\mathrm{X}_{it} + \mu_{it} \tag{2}$$

where FV_{it} is the firm value in firm $i = 1, \ldots, N$, year $t = 1, \ldots, T(i)$.

G_{it} is the vector of generation of innovation variables.
D_{it} is the vector of dissemination of innovation variables.
S_{it} is the vector of strength of innovation variables.
X_{it} is the R&D expenditure.
δ_{jit} is the firm specific year dummy variables.
η_i is the individual specific constant or the firm effect.
μ_{it} is a classical disturbance term with $\mathrm{E}[\mu_{it}] = 0$, $\mathrm{var}[\mu_{it}] = \sigma_\mu^2$.

There are $N\delta_{jit}$ indicators, one for each unit in the analysis. Equation (2) does not include a general intercept α to avoid perfect collinearity with the set of N indicators δ_{jit}. For the obvious reasons, Eq. 2 is often called the LSDV (Least Squares with Dummy Variables) model.

4. Empirical Results

Table 3 reports the descriptive statistics. The time series observations for all the cross-section units can be pooled and the regression coefficients can be estimated by OLS. As a matter of fact, prior research in the literature (refer to Sec. 2) used both OLS as well as pooled OLS regression. However, using OLS to estimate the co-efficients has two drawbacks. First, errors in the model may be autocorrelated. The second drawback is that the variance of the error term may not be constant over time. To overcome the second drawback, White's robust heteroscedasticity corrected covariance matrix was used in the fixed-effects model. To examine whether the fixed-effects (FE) model is superior to the pooled OLS, we tested the joint significance of the dummies by performing an F-test.

$$Ho : \eta_1 + \eta_2 \cdots \eta_n = 0,$$

Table 3. Descriptive statistics.

	Mean	Std. Dev	Min	Max	No cases
R&D	214.35	452.796	1.113	4006	553
CII	1.38493	0.88392	0.121	7.55258	576
PAT	92.599	162.706	1	1469	576
TECH	143.308	339.320	0.403	3731.113	576
MKTVAL	7147.54	21524.8	29.172	275006	572

Under the null hypothesis, the model becomes the pooled regression, i.e. $Y_{it} = \lambda_i + \beta' X_{it} + u_{it}$.

Under the null hypothesis,

$$F = \frac{(SSR_{pooled} - SSR_{fixed\ effects})/(n-1)}{SSR_{fixed\ effects}/(nT - n - k)} \sim F_{n-1,\ n(T-1)-k}$$

In Tables 4, 5 and 6 we present the model selection test (F-stat). In all the three cases, the F-statistics are significant indicating that the fixed-effects model is preferred to pooled OLS. Thus, our discussion will be focusing on the fixed-effects model.

In Table 4, regression results of the R&D for 64 firms are reported. Parameter estimates of R&D were strongly positive and significant in the one-year lag and three-year lag. This confirmed our expectation that R&D spending positively impacts the firm value immediately as well as over time. To further investigate the impact on various components of R&D on the firm value, we regressed various other independent variables. In the fixed-effects model, the number of patents (PAT), a proxy for innovation generation, was positive but not significant in the one-year lag. However, PAT was highly positive and significant when we tested with a three-year lag. This indicates that patent applications impact the market value of firm with a time-lag. This is reasonable when one considers the corporate reality that investments in firm innovation and knowledge involve a lead time before the payback occurs.

In terms of innovation dissemination, the fixed-effects model in Table 5 provides some interesting results too. Current Impact Index (CII), which indicates the impact and citation frequency of a firm's patents, is negative and insignificant in the one-year lag. However, with a three-year lag the coefficient becomes highly positive and significant. Table 6 provides regression results for technology strength (TECH), a proxy for innovation strength. It appears that for the fixed effects model, TECH is positive but insignificant in the one-year lag. In the three-year lag TECH becomes positively significant at the 1% level.

Again, these findings support our notion that investments in technology require time to pay back. Research evidence exists to show that CII positively impacts firm performance which is reflected in long-term appreciation in firm value (Wolff, 1998; Breitzman and Thomas, 2002).

5. Conclusion

This study attempted to examine factors that determine the technological innovation profile of a firm. By using data that originated from firm level patenting activities, we were able to create such a profile consisting of generation, dissemination and strength of a firm's innovation.

Table 4. Regression results of R&D.

	1-year lag		3-year lag	
Variable	OLS	Fixed effects	OLS	Fixed effects
Constant	−1572.97***		−102.17	
R&D	41.43***	47.21***	45.22***	13.69***
Adj. R^2	0.73	0.82	0.599	0.841
F-Statistic	1516.78***	41.62***	826.77***	47.36***
Model selection test (F-stat)		14.32***		44.02***

Note: ***, **, * denote significance at 1%, 5%, and 10%, respectively.

Table 5. Regression results of R&D, patent and citation impact index.

	1-year lag		3-year lag	
Variable	OLS	Fixed effects	OLS	Fixed effects
Constant	−2987.23***		−3965.26***	
R&D	42.26***	42.11***	47.06***	11.62***
PAT	−3.68	7.23	−8.32	10.95**
CII	1140.37**	−179.99	3051.48***	2132.38**
Adj. R^2	0.735	0.834	0.609	0.843
F-Statistic	509.72***	43.40***	287.54***	46.66***
Model selection test (F-stat)		14.31***		44.22***

Note: ***, **, * denote significance at 1%, 5%, and 10%, respectively.

Table 6. Regression results of R&D and Tech.

Variable	1-year lag OLS	1-year lag Fixed effects	3-year lag OLS	3-year lag Fixed effects
Constant	−1989.64***		−560.26	
R&D	37.95***	42.334***	41.37***	10.81
TECH	7.84***	11.900	8.68***	7.03***
Adj. R^2	0.744	0.837	0.607	.84405
F-Statistic	797.97***	45.03***	427.60***	47.68***
Model selection test (*F*-stat)		14.12***		44.30***

Note: ***, **, * denote significance at 1%, 5%, and 10%, respectively.

We also aimed to predict the market value of a firm using these dimensions of technological innovation using a panel data methodology. Our findings support the resource-based view of the firm (Barney, 1991) and the dynamic capabilities framework (Teece *et al.*, 1997) and indicated that a relationship exists between innovation capabilities of a firm and its market value in the long run. While the OLS results seem to ignore the time factor, our fixed-effects model shows that a lagged relationship exists between innovation and market value. We believe that our study supports the notion that firms' investments in R&D take time to deliver returns. The results also show that stock market reaction for firm R&D strategy is long-term oriented.

Though this study did not provide comprehensively conclusive results, we believe that it provides some useful insights into the relationship between technological capabilities of a firm and its market value. The predictor variables *innovation generation, dissemination and strength* were significant predictors of the *firm value* with a three-year lag. Thus, we find support for Hypotheses 1, 2 and 3 with a time-lag of three years. Another explanation for the lagged effect on firm valuation is the fact that many US firms are filing for patents a great deal more than in previous years, and many of those patents almost encircle the actually "important" patents, thus their contribution to the true body of knowledge and eventually firm value may be effective only after a few years.

The limitations of the study are apparent. First, we only examined US firms, and an international comparison could provide vastly different results. Second, due to missing data, our sample size and time frame were somewhat limited. While we were moderately successful in identifying a pattern, we realise that additional data along with some new dimensions of a firm's technological strength such as "management" of a firm's innovation profile could possibly shed better light on this issue. Finally, many firms rely less on patenting and more on secrecy to protect their innovations, and those types of innovations could not be captured with our current means of analysis (McMillan *et al.*, 2000).

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