IT and Product Variety: Evidence from Panel Data

(Draft – Comments Welcome)

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Abstract

This paper examines the relationship between information technology (IT) and product variety. Consistent with prior theoretical work, we argue that IT and product variety are complements. IT innovations such as computer aided design and flexible manufacturing technology have enabled firms to offer greater product variety at a reasonable cost. Similarly, firms seeking to offer greater variety can facilitate this strategy through IT investment. Using a novel approach to measuring product variety at the firm level through trademark counts we examine the relationship between IT and variety in four ways: direct correlations, IT and variety demand estimation, productivity analyses, and market value analyses. We utilize an 11-year panel data set of information technology capital stock, trademark holdings and other measures for 512 Fortune 1000 firms to test our hypotheses. Overall, we find that IT is found to be associated with increased product variety, and that increased product variety increases demand for IT investment. Complementarities between IT and product variety are not significant in the productivity analysis but appear strongly when we consider their influence on firm valuation.

Key words: IT productivity, product variety, trademark, competitive advantage

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1. Introduction

One of the most critical decisions firms face is the amount of product variety (PV) to offer. PV decisions are closely tied to almost all other managerial decisions, including production and manufacturing planning, inventory policy, marketing, sales, research and development, and acquisition strategy. Because maintaining a diverse product line raises overall costs along a number of dimensions (Skinner 1974; Banker et al. 1990; Fisher and Ittner 1999), firms have typically limited their PV for efficiency reasons. However, in recent years we observe an explosion in the number of products offered in the marketplace (Pine 1992). A variety of information technologies (IT) ranging from flexible manufacturing, automated inventory management systems, retail point of sale systems and new distribution methods (on-line product configuration and ordering), have dramatically reduced the cost of offering a broad product line (Forza and Salvador 2002), enabling firms to offer greater consumer value and thereby increase profits (see e.g., Hausman 1997; Brynjolfsson, Smith and Hu 2003).

This research is based on the observation that IT investment and PV are complementary decisions (as per Milgrom and Roberts 1990): greater demand for PV encourages firm to invest in information technology to manage the costs of PV, while increasing availability of information technology has enabled firms to pursue greater PV as part of their market strategy. Complementarities manifest themselves in empirical data in two ways. First, complementary practices should appear together in firms pursuing profit maximization – in other words, the use of different complements should be correlated. Second, to the extent that some firms experiment, make mistakes or are unable to achieve the optimal levels of investments in all complements,[1] firms that can combine complementary investments should show higher performance than those that do not. Our specific research questions focus on the implications of complementarities between information technology and PV. In this paper we focus on two specific questions that arise from this relationship:

1) Is product variety at the firm level related to information technology investment?

2) Do firms that combine greater product variety with higher levels of IT investment achieve greater value than other firms?

[1] See Bresnahan, Brynjolfsson and Hitt (2002) for a discussion of this issue in the context of complementarities between information technology and skilled labor.

These questions are relevant both at a managerial level in assessing the required investments to offer greater PV and also at the macroeconomic level, enabling a better understanding of the drivers of the observed increase in product variety that has appeared in the global economy (Pine 1992). Addressing these questions also can shed light on a key point of debate on the value of IT – the extent to which increased intangible output, in the form of greater variety, represents a significant source of unmeasured IT value (Brynjolfsson 1993; Brynjolfsson and Hitt 2000).

There has been extensive research on the PV decision, especially in the marketing, strategy and operations management literature. However, empirical research in this area is quite limited due to the difficulty of measuring PV. Studies have either examined highly aggregate measures (e.g., industry diversification as in Rumelt 1974 or Montgomery 1982) or micro-level context specific measures such as "stock keeping units" (SKUs) (Fader and Hardie 1996) or sizes, colors or configurations of a single product (Randall and Ulrich 2001). The measurement of variety through diversification is the principal focus of much of the IT literature in this area, especially research focusing on coordination costs and firm boundaries (Malone et al. 1987; Gurbaxani and Whang 1991; Clemons and Reddi 1993; Brynjolfsson et. al. 1994; Hitt 1999).

Our principal empirical contribution in this research is in developing a new measure of PV based on trademark counts. Trademark counts are naturally associated with PV as they represent the diversity of trade names used to represent a firm's products to the marketplace. These data have the advantage of being readily measurable through publicly available data, yet sufficiently comparable across firms to enable meaningful comparisons across firms and industries. The idea of capturing PV through trademark counts was first suggested by Brooke (1991) who examined the relationship between IT and PV at the economy level. We have extended this approach to the firm level, enabling us to link PV to other data commonly used to study the value of IT.

To the best of our knowledge, this is the first large sample empirical paper focusing on the relationship between IT and firm-level PV. We use an 11 year (1987-1997) panel data set of information technology capital stock, trademark holds and relevant control variables for 512 of Fortune 1000 firms to test our hypotheses. Our results suggest that IT and product variety are indeed complementary – firms with greater IT intensity (controlling for other factors) tend to have greater product variety and firms that pursue a high product variety strategy and invest heavily in IT have greater market valuation than firms that pursue only one of these complements.

2. Literature Review

2.1 Product variety

Research on PV can be divided into two categories: within-industry variety (differentiation) and between-industry variety (diversification). The economics of differentiation can be traced back to Hotelling (1929) and Chamberlin (1933). This research concentrated on the socially optimal degree of differentiation in oligopoly settings (Lancaster 1990; Spence 1976; Dixit and Stiglitz 1977) and was not particularly concerned with differentiation strategy. The strategic implications have been pursued by the management literature (Rumelt 1974), especially in research on firm level diversification and performance. This literature has advanced several ideas on why diversification may improve performance. These explanations include enabling firms to exploit scalable resources (Teece 1982; Montgomery and Wernerfelt 1988), reducing risk (Amihud and Lev 1981), and creating tax advantages (Majd and Myers 1987). However, industry diversification is a considerably higher level choice than product variety which is typically made within a specific market.

Theoretical and empirical analysis of the differentiation decision has been pursued in both the marketing and operations management literature. Marketing research has examined consumer choice in the presence of differentiation (Fader and Hardie 1996), consumer variety seeking behavior (Feinberg, Kahn, and McAlister 1992), and the resulting outcomes in terms of market share of competing sellers (Kekre and Srinivasan 1990; Bayus and Putsis 1999). Research in operations management has focused on the production process required to provide product variety including the impact on design (Ramdas 2003), internal operations (Fisher and Ittner 1999; Bradley and Thonemann 2002), and supply chain efficiency (Randall and Ulrich 2001). However, much of this literature relies on very specific definitions of variety unique to particular settings.

2.2 Information technology and product variety

Higher product variety may increase price and market share, but may also cause firms to incur higher production costs (Banker et al. 1990) and increase the costs of related, information-intensive tasks such as planning, design and quality control (Miller and Vollmann 1985; Fisher et al. 1995). It is widely known that IT has a great potential to drive down these costs (Malone et al 1987; Gubaxiani and Whang 1991). For instance, research has found a direct link between EDI and efficiency in logistics (Srinivasan, Kekre and Mukhopadhyay 1994), and others have found that more efficient intra-firm communications lowers the cost of providing a varied product line (Pine et al. 1993). IT can also influence the costs of other activities required for firms to offer greater variety such as managing customer data (e.g., customer relationship management systems), communicating product characteristics to consumers (e.g, supplier intranets, online review systems), and managing the design process (e.g., computer aided design systems). IT facilitates the formalization, storage and spread of knowledge (Liberatore and Stylianou 1995), which boosts innovation and improves the product development process (Krishnan and Ulrich 2001). A synthesis of these observations is provided by Milgrom and Roberts (1990) who observed that the shift from mass production to high variety "modern manufacturing" is driven by the price decline in information technology.

2.3 Macroeconomic observations about IT and variety

During the past two decades, firms have been investing heavily on IT. Business capital stock of "Office, Computing and Accounting Machinery" has risen from less than 1% of equipment stock in 1979 to more than 5% in 1989, and these investments account for over 10% of new investment in capital equipment in US (Oliner and Sichel 1994). Meanwhile, the quality-adjusted price of IT has been dropping at annual rate of 20-30% (Berndt and Griliches 1990). These trends are well understood and have formed the backbone of much of the research on the macroeconomic implications of information technology.

A less studied and perhaps equally interesting trend is that this diffusion of IT has also occurred over a period where product variety has been dramatically increasing. The number of new product introductions in supermarkets has grown from 1,281 in 1964 to 16,790 in 1992 (Nakamura 1997). While this trend is well established as important, it is less understood what has driven this change. Brooke (1991) observed that variety was steadily increasing alongside IT investment, which suggests a relationship between IT and product variety.

3. A Simple Complementarities Model of IT and Product Variety

To illustrate the arguments we have advanced about IT and product variety, we construct a simple 2-stage dynamic model to study the relationship between IT and PV. The stages are as follows:

Stage 1: A firm invests in IT to increase its abilities of dealing with PV-related costs, which we define as PV capacity, *F*.

Stage 2: Firm decides how much PV (denoted as V) to increase.

We divide the impacts of *V* on profit in two parts – benefits denoted as *B(V)* and costs denoted as *C(V; F)*. Note that the costs depend on the capacity choice. Thus, the second stage profit is

$$\Pi_2 = B(V) - C(V;F)$$

The marginal cost of product variety is $\frac{\partial C}{\partial V}$. Because IT investments reduce the costs of product variety (in ways specified by Miller and Vollmann 1985, and Fisher et al. 1995), we naturally have $\frac{\partial^2 C}{\partial V \partial F} < 0$, and thus $\frac{\partial^2 \Pi_2}{\partial V \partial F} > 0$. Thus $\Pi_2(V;F)$ is supermodular with respect to its arguments. This means that other things equal, firms with higher IT investment find it profitable to have more PV. This is consistent with researches on IT-enabled competitive advantage which argue that product innovation is one of the opportunities for IT to support competitive strategy (Bakos and Treacy 1986; Wade and Hulland 2004; Pavlou and El Sawy 2004). Denoting the profit maximizing level of variety in the second stage as *V** we have

Proposition 1. V^* will monotonically increase with F.

Proof. Follows directly from Topkis (1978) since Π_2 is supermodular in V and F.

Returning to Stage 1, we now compute the optimal investment in *F*. The total profits would be $\Pi_1 = \Pi_2^*(F) - K(F;P_{IT})$, where $\Pi_2^*(F) = \underset{V}{\mathrm{Max}}\, B(V) - C(V;F)$ and $K(F;P_{IT})$ is the cost of building up flexibility capacity *F*. Naturally, $\frac{\partial K}{\partial F} > 0$. However, if the price of IT decreases, achieving the same capacity for flexibility will be less costly, thus we have $\frac{\partial^2 K}{\partial F \partial P_{IT}} > 0$, which leads to $\frac{\partial^2 \Pi_1}{\partial F \partial P_{IT}} < 0$. This means that $\Pi_1(F; -P_{IT})$ is supermodular with respect to its arguments.

Proposition 2. Decreasing IT price will boost both investment in flexibility and product variety.

Proof. Decreases in P_{IT} cause an increase in F at optimum from the supermodularity of $\Pi_1(F; -P_{IT})$. This in turn causes an increase in V from Proposition 1.

The above model shows that under very mild assumptions, falling price of IT should drive monopoly firms to increase both IT investment and PV. However, this same intuitive result may not necessarily extend to oligopolistic settings as competitors' investments in variety may decrease the marginal benefit term, thus decreasing the benefits of further investments in variety. Thus, whether or not product variety and IT are complements is ultimately an empirical question, which we will pursue in depth in the following sections.

4. Econometric Model and Data

4.1 Model

Our hypothesized complementarity relationship between IT and product variety can be tested in several ways.

4.1.1. Correlations between IT capital and product variety

If IT and PV are complements, they should covary in both the cross-section and time series dimensions of our panel data set. Given that price of IT steadily and exogenously declines over time, there is strong reason to believe that a significant portion of the variation in IT investment is exogenous and thus we are observing a natural experiment in which variety responds to changes in IT investment. However, it may be equally likely that short run changes in the benefits of variety (e.g., due to competition or changes in consumer taste) may also cause incremental investment in IT. From a theoretical standpoint, the complementarities relationship implies mutual causation; however, it may be interesting to distinguish these two causal directions and the time over which they act. To accomplish this, we examine correlations between IT and product variety at different leads and lags. These correlations will be performed controlling for factors such as industry, size and time to remove the influence of external factors not related to the relationship between IT and variety.

4.1.2 System of demand functions

An alternative approach is to create a demand system that simultaneously estimates the drivers of both PV and IT demand. In order to separately identify the causal directions between IT and variety, we must identify instrumental variables that affect one of the complements but not the other. For instruments for IT we propose that a firm's ability to invest incrementally in IT depends on the characteristics of their IT and production infrastructure. We capture IT infrastructure using a measure of the number of PCs (*PC*) and the number of mainframe terminals (*Term*). A firm with greater numbers of PCs relative to terminals is likely to have a more modern and flexible client-server IT infrastructure. We also measure age of a firm's capital (*CapitalAge*) which is indicative of how likely the firm is to have computer-controlled production technology. For instruments for product variety, we note that if a firm's competitors are offering greater variety, the firm may be compelled to offer greater variety as well. We therefore instrument product variety with a measure of variety of other firms in the same industry (*PV_Other*). We also include control variables for time, industry, firm diversification (using the entropy index utilized in prior work[2] – *Entropy*), size (*Sales* and *Capital*). This yields the following demand system (with all variables in logarithms except time, industry, and entropy):

$$IT = \alpha_0 + \alpha_1 PV + \alpha_2 Capital + \alpha_3 CapitalAge + \alpha_4 PC + \alpha_5 Term + \alpha_6 Sales + \alpha_7 Entropy + industry + year + \varepsilon_1$$

$$PV = \beta_0 + \beta_1 IT + \beta_2 PV\_Other + \beta_3 Capital + \beta_4 Sales + \beta_5 Entropy + industry + year + \varepsilon_2$$

These equations can be estimated using three stage least squares (3SLS) to separate out the causal direction (provided our instruments are correct). Recognizing our instrument set may be far from ideal, we also run corroborating regressions using Seemingly Unrelated Regression

[2] Following Jacquemin and Berry (1979), we adopt entropy as a measure of diversification. Suppose a firm is active in N 4-digit industries, the entropy is calculated as: $Entropy = \sum_{i=1}^{N} p_i \ln \frac{1}{p_i}$, where p_i is the portion of the firm's total sales within industry i . These data are obtained from Compustat Industry Segment database.

(SUR) and Ordinary Least Squares (OLS) that can be interpreted as conditional correlations, similar to our earlier correlation results.

4.1.3 Productivity

If IT and product variety are complements, then firms that invest in both together should show higher performance than those who make these investments in an uncoordinated fashion. Following the approach of Hitt and Brynjolfsson (1996) we link value-added (sales less materials) to several inputs: ordinary capital stocks, computer capital stocks, labor and product variety.

$$ValueAdded = \beta_0 + \beta_1 IT + \beta_2 PV + \beta_3 IT * PV + \beta_4 Capital + \beta_5 Labor + \beta_6 Entropy + industry + year + \varepsilon$$

In this equation, we are especially interested in the interaction term *IT*PV*, whose sign should be positive if IT and PV are complements.

4.1.4 Market value

Finally, we consider evidence of complementarity between PV and IT using stock market valuation (following Brynjolfsson, Hitt and Yang 2002). Using their base equation which relates stock market value to IT capital, property plant and equipment (*PPE*), and other assets (*OtherAssets*), we add additional variables for product variety, its interaction with IT and an additional control for firm diversification. This yields:

$$MarketValue = \beta_0 + \beta_1 IT + \beta_2 PV + \beta_3 IT * PV + \beta_4 PPE + \beta_5 OtherAssets + \beta_6 Entropy + industry + year + \varepsilon$$

If IT and PV are complements, their combined value should be higher than the sum of isolated values and the interaction term (IT*PV) should be positive.

4.2 Data construction

Our data set consists of three sources: (1) a panel of large firms detailing IT capital levels over the 1987-1997 period; (2) trademark data over the 1987-1997 period from United States Patent and Trademark Office; (3) Compustat measures of other production function inputs and outputs over the 1987-1997 period. After omitting firms from our raw data which had incomplete or anomalous data, and those which had missing data other than at the beginning or end of the measurement period, 512 firms remain in our sample, with total observations of 3927 firm-year observations. Here we briefly describe each data source and our measures of key variables.

4.2.1 IT capital

Our measures of IT use were derived from the Computer Intelligence Info Corp (CII) installation database. CII conducted a telephone survey to inventory of specific pieces of IT equipment by site for firms in the Fortune 1000 (surveying approximately 25,000 sites). For our study, CII aggregated types of computers and sites to get firm level IT stocks. However, the IT data do not include all types of information processing or communication equipment and are likely to miss a portion of computer equipment which is either purchased by individuals or departments without the knowledge of information systems personnel, or owned or operated off-site. The IT data also excludes investments in software and applications. Descriptive statistics are in Table 2.

4.2.2 Measurement of PV

Measurement of PV has been a difficult and controversial issue in economics, marketing and strategic management research (Gans and Hill, 1997; Sambharya, 2000). A variety of approaches have been used including subjective strategy classification (Rumelt 1974); SIC based measurements (Montgomery 1982); product line measures (Kekre and Srinivasan, 1990); and SKU-based measures (Fader and Hardie 1996).

The first two categories principally capture diversification but not differentiation, while the latter two categories combine both but with some limitations. The most important limitation is that they are specific to a particular market and therefore cannot be used to compare variety across different types of firms. Following Brooke (1991), we argue that trademark counts can be a good index of overall PV. There are several advantages of trademark data:

1) Compared to product count measurements, trademark reflects non-trivial variation among products.

2) Compared to SIC counts, the trademark count contains more information of product differentiation. For instance, all automobile manufacturers are in the auto industry (SIC3711), but trademarks capture the distinctions between brands (e.g., Ford, Mercury, Lincoln) and models (e.g., Taurus, Bronco).

3) Trademarks are closely related to brand identity and marketing strategy, so trademark counts may better reflect active investments in marketing.

4) Trademarks are publicly available over a very large time span (from 1884 to present) and include a wide scope of products across all industries.

Our measure of trademark counts is based on an analysis of trademark registration data provided by the US Patent and Trademark Office. We take the company name that appears on the registry and link it to the ultimate parent firm using the Compact Disclosure Database. Our key measure of product variety is the count of trademarks currently registered to a firm in a particular year.

To examine the properties of trademarks relative to diversification measures, which have been previously employed in other firm-level research, we calculated several commonly used diversification measures for our data: entropy, count of 4-digit SIC segments that a firm participates, and diversification index developed by Montgomery (1982). Interestingly, while different diversification measures are highly correlated with each other, they are not strongly correlated with trademarks (see Table 3). This suggests that trademarks contain information not included in the diversification measures. Nonetheless, we include a control variable for diversification (using the entropy measure) to ensure that our empirical results principal relate to differentiation. In addition, we examined a small sample of the specific trademarks in our database – this information analysis suggests that much of the variation in trademark level is related to breadth of product line within a market.

However, trademark counts are not immune to some of the difficulties of other differentiation measures. Like SKUs and some product line specific measures, trademark counts weight all products equally despite potentially large differences in value. Second, not all variety may be captured by trademarks as many firms offer multiple products under the same trade or service mark. With the above limitations in mind, we believe that this relatively untapped source of information on product variety can significantly increase the understanding of the role of product variety in modern firms.

4.2.3 Other data

Other data such as industry, value-added, employment, sales, market value, and other control variables can be derived from Compustat following well established procedures from the IT and productivity literature. See Brynjolfsson and Hitt (2003) for construction of the productivity-related measures and Brynjolfsson, Hitt and Yang (2002) for a discussion of the market-value related measures. Tables 1 and 2 provide summary statistics. Overall, our sample is in general comparable to the population from which it was drawn (Fortune 1000) and collectively accounts for about 10% of the value-added in the US economy.

5. Results

5.1 Correlations

We calculate the spearman correlation between IT and PV conditional on industry and year using both current period values and with one variable lagged up to four years. We find a significant positive correlation between IT and PV. The correlation coefficients range from 0.275 (current value) to 0.237 (four year lag), which are significant at 1% level (Table 4).

To further control for the unobserved heterogeneity, we repeat the analysis using 1-year time differences in IT and trademarks. This technique removes time invariant differences among firms from the analysis and thus isolates the time dimension more effectively. Even in this much more stringent test, the correlation between contemporary IT and PV remains significant at 1% level. This is likely driven by the fact that IT investment is relatively easy to adjust, so when firms expand PV, they will increase investment in IT as well. However, in the reverse direction, the results suggest it may take as long as 3 years for a change in IT to cause a resulting change in product variety. This is consistent with the idea that while IT levels can be readily adjusted, IT enabled changes may involve a considerable period of time before their full organizational impact can be realized. We also find that one year and two year lag of PV is positively correlated with IT. This suggests that an expansion in variety may require future investments in IT over several successive years.

5.2 Demand system

Examining the IT demand equation, we find that PV has consistent positive effect on IT demand. This relationship is positive in the OLS regression, and significant at $p<.01$ level in the SUR regression. In the 3SLS specification, we find PV's coefficient is much larger and significant at $p<.1$ level. One percent increase in PV is associated with 1.85 percent increase of IT. Among the covariates, we find that firms with older capital age tend to have less IT capital consistent with our prior assertions.

Examining the PV demand function, we find IT's coefficient is always positive and significant at $p<.05$ level. This means that firms with more IT tends to have more product variety. Both SUR and 3SLS regressions indicate that one percent increase in IT capital is associated with .169 percent increase in PV level. Sales also have a strong positive effect on PV, most likely due to effects of size. We also find that sum of trademark counts of other companies in the same 4-digit SIC segment is negatively associated with a firm's PV level. This is perhaps inconsistent with the idea that variety can become a competitive necessity in the market, although given that we are defining "market" fairly crudely through 4-digit SIC industries, we are reluctant to interpret this result too strongly.

Over all, the system equations show that there is a strong positive relationship between IT and PV, consistent with our correlation results, and supportive of our hypothesis that IT and PV are complements.

5.3 Productivity

Consistent with prior work, we estimate a production function that relates value added to capital, labor and IT capital, controlling for year and 1.5 digit SIC industry.[3] Because of repeated observations of the same firms over multiple years, we employ Huber-White robust standard errors for these estimates.

Our estimates are shown in Table 6. Column 1 shows the basic model, in which the explanatory variables are IT, Capital and Labor. In Column 2 we add PV and entropy into the model and find that product variety has a weakly positive but not significant impact on productivity. When we add the interaction term the interaction term log(PV)*log(IT) (see Column 3) we find that the interaction is positive but not significant. Thus, while there is clear evidence that IT creates incremental productivity benefits, it is less clear that trademarks or their interaction with IT yields significantly higher productivity. This could in part be due to measurement problems since the overall effect size of the productivity influence may be relative small compared to other unobserverable differences among firms or in the market over time. An alternative interpretation is that the small effect is due to the fact that productivity regressions are not good at capturing the benefits of variety (see Brynjolfsson and Hitt, 2000 for a discussion of the difficulties in

[3] We also explored regressions with finer control variables – these results were even more inconclusive.

measuring intangible outputs in productivity frameworks). However, while not inconsistent with our hypothesis, this provides little additional support.

5.4 Market value

The market value function relates market value to three types of assets: computers, property plant and equipment (*PPE*), and other assets (principally accounts receivable, inventories and liquid assets other than cash). We add PV, entropy and the interaction between PV and IT to the equation to test their influence to the market value.

Since we are pooling multiple firms in multiple years, we include 4-digit SIC dummy variables for each year and industry, which controls industry specific performance shocks. Our regression methods include OLS, Robust Regression and GLS. We also investigate how the correlation between IT and PV is driven by variation across firms, (a "between" regression) and variation for the same firm over time (a "within" or "firm effects" regression). If the model specification is correct, we should see the effects in both within and between models.

As shown in Table 7 Column 1 (OLS regression), we find that each dollar of installed property, plant and equipment (*PPE*) is valued at about $1.88. The market value of each dollar of other assets is around $1. Each dollar of IT capital is associated with about $25 of market value. These results are consistent to the findings by Brynjolfsson, Hitt and Yang (2002), although the coefficient on PP&E is somewhat larger than would be expected and the IT coefficient is slightly larger. When we add PV into the equation we find a significant impact of product variety on market value ($p<.01$). Each additional trademark is valued at around 6.43 million dollars. The coefficients of PP&E and Other assets remain almost the same.

When we add the interaction term between IT and product variety (Column 3), we find the interaction is positive and strongly significant ($p<.001$). The magnitude of the coefficient suggests that a firm that is one standard deviation above the mean in both IT and trademarks is worth 16% more than other firms. In Column 4, we repeat the prior analysis using robust regression and find similar results. Thus, while the results are inconclusive on the productivity measures, which reflect mostly short run performance, evidence suggests that market investors believe that these complementarities may create significant value over the longer term, consistent with our complementarities hypothesis. We also note that the diversification measure (entropy) is not significant. The above results are also robust across different regression specifications including within, between and random effects panel data models (not reported).

6. Discussion and Conclusion

Using a panel data of 512 large firms, we find empirical evidence that IT and PV are complements. Firms with higher PV level tend to use more IT, and firms with more IT capital have greater PV.

Our results are consistent with each of the testable implications of a complementarities relationship:

1) There exists positive correlation between IT capital and levels of PV;

2) PV and IT contribute positively to each other in the demand function system;

3) Firms with both higher levels of IT and higher levels of PV have higher measured productivity, although these results are not significant;

4) Firms with both higher levels of IT and higher levels of PV have higher market valuations than firms invest heavily on only one or the other dimension.

While each individual analysis is potentially affected by a variety of econometric and data problems, the consistency across multiple approaches gives us greater confidence in our results.

Our research contributes to the understanding of how IT contributes to current US economy. As a general purpose technology, IT contributes to the economy and welfare indirectly by enabling other complementary innovations to be made. Prior research has linked IT to organizational innovation. This research provides further evidence that IT is also related to marketplace innovation, an observation hypothesized but not directly tested by Bresnahan, Brynjolfsson and Hitt (2002). Our results are also consistent with prior assertions that IT-enabled product variety creates considerable value but that this benefit may not be easily captured in productivity measures. While we do not find the productivity decline due to variety hypothesized by Brooke (1991), our results do lend further evidence that intangible aspects of output may represent a significant and unmeasured productivity contribution of IT.

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Table 1: Sample composition

Industry	SIC	Sample%	Fortune%	Compustat%
Agriculture Mining, and construction	0-1999	3	5	7
Manufacturing	2000-3999	45	40	34
Transportation, Communications, Electric, Gas, And Sanitary Services	4000-4999	14	14	9
Whole Sale and Retail Trade	5000-5999	17	18	10
Finance, Insurance, And Real Estate	6000-6999	12	13	21
Services	7000-8999	7	10	18
Other	Other	1	0	1
Total		100	100	100

Table 2: Descriptive statistics of major variables

IT-related

	Unit	N	Mean	Std. Dev.
IT capital	$mm	3927	36.6	104.4
Number of PC		3927	4380	8665
Number of Terminals		3927	7032	16101

Source: CII
Note: IT capital is 1994 constant value

Product Variety-related

	N	Mean	Std. Dev.
Trademark count	3927	156.2	238.9
Four-digit SIC counts	2909	3.61	2.60
Entropy-measurement	2909	0.93	0.52

Source: Compustat

Production function and market value related

	Unit	N	Mean	Std. Dev.
Value-added	$mm	3790	2570	4869
Capital	$mm	3553	6757	13878
Sales	$mm	3926	6050	10812
Market Value	$mm	3926	13309	26458
PPE	$mm	3926	2580	5182
Other Assets	$mm	3926	7207	20423

Source: Compustat
Note: 1994 constant value

Table 3: Correlation between trademark measure and diversification measures

	Entropy	SIC count	Diversification Index	Log(trademark count)
Entropy	1.0000			
SIC count	0.8876	1.0000		
Diversification Index	0.9270	0.6931	1.0000	
Log(trademark count)	0.0152	0.0282	-0.0013	1.0000

Table 4: Correlation between IT and PV conditional on industry (4 digit SIC) and year

	No lag	1 year lag	2 year lag	3 year lag	4 year lag
PV~ lag (IT)	0.275***	0.261***	0.242***	0.239***	0.237***
IT~ lag (PV)	0.275***	0.269***	0.262***	0.255***	0.251***

One year difference

	No lag	1 year lag	2 year lag	3 year lag	4 year lag
PV~ lag (IT)	0.048**	0.018	0.011	0.078***	-0.021
IT~ lag (PV)	0.048**	0.143***	0.070***	-0.002	-0.009

Spearman partial rank order correlations controlling for industry (4 digit SIC dummy variables) and year.
Key: * - p<.1, ** - p<.05, *** - p<.01; test is against the null hypothesis that the correlation is zero.

Table 5: Demand equations

IT demand equation, Dependent variable: Log(IT)

Variable	OLS	SUR	3SLS
Log(PV)	.0119 (.0120)	.0494*** (.0115)	1.85* (1.04)
Log(Capital)	.0993*** (.0294)	.0984*** (.0282)	.103 (.219)
Log(Capital Age)	-.0714** (.0283)	-.0707*** (.0272)	-.0570 (.101)
Log(Sales)	.265*** (.0350)	.253*** (.0335)	-.325** (.162)
Log(Number of Terminals)	.114*** (.0143)	.113*** (.0137)	.0543*** (.0129)
Log(Number of PC)	.525*** (.0187)	.522*** (.0179)	.309** (.136)
Entropy	-.0288 (.0272)	-.0350** (.0262)	-.330* (.189)
R-square (adjusted)	.878		
Observations	2629	2629	2629

* -p<.1, ** -p<.05, *** -p<.01, standard error in parentheses
4-digit industry control

Product variety demand equation, Dependent variable: Log(PV)

Variable	OLS	SUR	3SLS
Log(IT)	.0592** (.0250)	.169*** (.0266)	.169*** (.0267)
Log(PV_Other)	-.238** (.118)	-.237** (.116)	-.237** (.116)
Log(Sales)	.387*** (.0340)	.287*** (.0354)	.287*** (.0354)
Entropy	.0849** (.0403)	.171*** (.0443)	.171*** (.0443)
R-square (adjusted)	.741		
Observations	2909	2629	2629

* -p<.1, ** -p<.05, *** -p<.01, standard error in parentheses
4-digit industry control

Table 6: Productivity

Log(Value Added)	Base	Add PV	Add IT*PV
Log(IT)	.0596*** (.0150)	.0585*** (.0148)	.0594*** (.0147)
Log(PV)		.0116 (.0119)	.0118 (.0116)
Log(IT)*log(PV)			.00808 (.00808)
Log(Capital)	.236*** (.0211)	.240*** (.0216)	.237*** (.0219)
Log(Labor)	.648*** (.0341)	.639*** (.0352)	.639*** (.0352)
Entropy	.0212 (.0294)	.0196 (.0291)	.0182 (.0295)
Controls	Industry Year	Industry Year	Industry Year
R-square (adjusted)	0.881	0.882	0.882
Observations	2613	2613	2613

* -p<.1, ** -p<.05, *** -p<.01, standard error in parentheses
1.5-digit industry control

Table 7: Market value

Market Value	OLS	OLS	OLS	Robust Regression
PPE	1.88*** (.142)	1.81*** (.138)	1.70*** (.139)	1.25*** (.00938)
Other Assets	1.05*** (.0174)	1.04*** (.0168)	1.03*** (.0144)	1.02*** (.00132)
IT (centered)	25.4*** (4.95)	24.2*** (4.93)	19.2*** (4.12)	12.0*** (.321)
PV (centered)		6.43** (2.53)	4.74** (.2.40)	1.76*** (.142)
IT*PV			.0533*** (.0168)	.0696*** (.000982)
Entropy		468 (321)	205 (315)	-34.2 (43.3)
Controls	Industry Year	Industry Year	Industry Year	Industry Year
R-square (adjusted)	.974	0.975	0.976	
Observations	2909	2909	2909	2909

* -p<.1, ** -p<.05, *** -p<.01, standard error in parentheses
4-digit industry control