Investments in Modernization, Innovation and Gains in Productivity: Evidence from Firms in the Global Paper Industry

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This version: January 2008

Abstract
This paper examines the impact of investments in modernization and innovation on productivity in a sample of firms in the global pulp and paper industry. This industry is important because it has traditionally accounted for significant amounts of employment and capital investment in North America and Europe. In contrast to much of the existing literature which focuses on the impact of R&D and patents on firms' performance and productivity, we examine data on actual investment transactions in four main areas of operations: (i) mechanical, (ii) chemicals, (iii) monitoring devices and (iv) information technology. We find that firms which made decisions to implement a greater number of investment transactions in modernization achieved higher productivity, and these estimated quantitative effects are greater than the impact of standard innovation variables such as patents and R&D. Investment transactions in the information technology and digital monitoring devices imparted a particularly noticeable boost to productivity. These results are obtained after controlling for other firm-specific variables such as capital-intensity and mergers and acquisitions. Two broad messages emerge from our study. First, firms' decisions to undertake investments in modernization and various forms of incremental innovations appear to be critical for achieving gains in productivity. While these may typically generate small gains on a year-to-year basis, they can compound to form meaningful differences in performance, productivity and competitive position across firms in the longer-run. Second, for some of the traditional industries like pulp and paper, R&D and patents seem to be particularly poor indicators of innovation and, more generally, how firms go about achieving gains in productivity. While this paper focuses on the pulp and paper industry, our broad framework and methodology is general and can be applied to understanding firms' strategies related to enhancing performance and productivity in a variety of industries.
JEL Codes: D20, L20, L60, M10.
Keywords: Pulp and paper industry; investment; modernization; innovation; productivity; organizational behavior.

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This study was funded by a 2004-2006 grant from the Center for Paper Business and Industry Studies, an Alfred P. Sloan Foundation Industry Research Center. The grant was to examine "The Role and Value of Innovation in the Pulp and Paper Industry" and is part of the Sloan Foundation's initiatives to gain an understanding of innovation, productivity and competition issues in important traditional industries. For helpful comments, we thank participants at the TAPPI Engineering, Pulping & Environmental Conference, Competitive Advantage Conference and the *CESifo* workshop on "Productivity and Growth."

1. Introduction

Improving productivity is at the core of a firm's business strategy. Higher productivity is likely to improve profitability and enhance a firm's competitive position relative to its rivals. There are alternative strategies a firm can pursue to improve its productivity. These include: (1) pursuing a path of pure innovation captured by variables such as R&D expenditures and patents granted; (2) make decisions to invest in physical capital that modernize and upgrade production capabilities; (3) engage in mergers and acquisitions to reap economies of scale and scope and generate other synergies; and (4) make changes to its organizational structure, better management and improve its supply-chains. While a firm can potentially pursue all of these strategies, which one is likely to be more successful, or viable, depends, in part, on market conditions and the industry the firm operates in.

Our focus in this paper is on the global pulp and paper industry. A defining characteristic of this industry is that the basic technology used for producing paper is quite old and well known. While recent decades have seen changes in the sophistication of equipment and machines and the incorporation of digital devices and information technology, this is not an industry where a firm can typically expect to make a breakthrough innovation to distance itself from its rivals.[1] In our sample of pulp and paper firms from North America, Europe and other regions, the "typical" firm has an R&D intensity of about 0.5% and the number of patents granted is low at about 2 per year. These numbers are underwhelming; R&D and patents, at least as conventionally measured, seem unlikely to be the major avenues for productivity gains. In this sense, firms in this industry are more likely to be able to achieve gains in productivity via

[1] See Ghosal and Nair-Reichert (2007) for details about the nature of technologies in the pulp and paper industry.

strategies of modernization and upgrading of production processes, incremental innovations that arise from learning-by-doing and possibly mergers and acquisitions.

The global pulp and paper industry has undergone significant changes since the late-1980s.[2] The global economic downturn in the late-1980s and early-1990s produced downward pressure on prices of paper products and sharp compression in firms' profitability. Firms were saddled with significant overcapacity due to low demand. Changing environmental standards forced firms in many countries to make new and costly investments to reduce pollution in order to meet the new regulatory standards. More open global markets and reduced ocean-freight rates allowed firms to enter new markets and compete. The overall effect was that firms in the pulp and paper industry faced a new economic environment and increased competitive pressure. To survive in this new environment, they had to carefully think through their business strategies in order to stay competitive and improve their bottom-line.

As we examine the behavior of the firms in the pulp and paper industry, we find that many engaged in a significant number of M&As, presumably with the objective of consolidating their position in the market, potentially reaping economies of scale and scope, and weeding out competitors as evidenced by post-merger plant closings.[3] To improve their competitive position, many firms also engaged in investments that modernized their production facilities, improved innovation outcomes, implemented changes in the supply-chain and their organizational

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[2] See Ince (1999), Douglas (2001), Engel (1997), Ghosal (2003), Ghosal and Nair-Reichert (2007), Kates (2002), McNutt (2002), Nair-Reichert (2002) and Suhonen (2001). Ohanian (1993, 1994) presents a historical perspective of some of the changes in this industry.

[3] See Kates (2002) for plant closings. Pesendorfer (2003) examines M&As in the U.S. pulp and paper and evaluates the effects on firms' investment decisions, costs, and consumers. Among his findings are that the merged firms are likely to scrap capacity subsequent to an acquisition.

structure.[4] In a broad sense, the firms appear to have adopted a two-pronged strategy of improving efficiency via modernization and incremental innovations, and engaging in M&As.

The objective of this paper is to examine in detail the outcomes of some of these strategies. Some of the questions we seek to answer are:

- Did the strategies to modernize and update production processes improve the performance and productivity of the firms?
- Did M&As improve productivity?
- Which strategy worked better?

This paper contributes to our understanding of business strategies pursued by firms in the global pulp and paper industry by developing a framework within which we conceptualize the evaluation of productivity gains and compile an extensive dataset from myriad sources to quantify the impacts.

Our main findings are that investments in modernization and upgrading of the production processes pay off in terms of higher firm-level productivity. The estimated quantitative impact on productivity of these investments is greater than the gains obtained by pursing a path of more innovation as measured by R&D expenditures and patents.[5] M&As appear to have little or no effect on productivity. In general, the gains in productivity via modernization and upgrading investments are not large. While the year-to-year gains are somewhat modest, the important point to note is that these modest gains can compound over time to form meaningful differences

[4] See Bjorkman, et al. (1997), Ghosal (2003) and Nilsson et al. (1995) for some details about the pulp and paper firms. The role of various types of innovations have been formally discussed by Audretsch (1995), Gort and Klepper (1982) and Winter (1984).

[5] For various facets of the standard literature on R&D and patents and empirical findings, see Audretsch (1995), Cohen and Levin (1989), Griliches (1984), Sutton (1997) and Winter (1984).

across firms. Therefore, managers of firms need to stay focused and emphasize the incremental gains in productivity to maintain or enhance their competitive position in the longer-run.

While the issues we discuss and our framework and data are for the firms in the pulp and paper industry, the conceptual framework we outline is general enough to be applied to examining business strategies related to productivity and innovation at the firm-level in almost any industry.

The paper is organized as follows. Section 2 provides information about the industry. In section 3 we discuss the production process and technologies, outline our categorization of investments in the key areas and provide details about the extensive dataset we compiled. Sections 4 and 5 describe the framework for examining firm-level differences in productivity and the firm-level data from the Compustat and Thompson's Financial databases. The results of our regression analysis are presented in sections 6 and 7. Implications and concluding remarks appear in section 9.

2. Industry Basics

We begin by providing a brief outline of the industry and the production processes. Paper is manufactured from wood, a natural and renewable raw material. Pulp – the basic ingredient for the manufacture of paper and board – is produced from fresh wood, woodchips from sawmills, recovered paper, sometimes from textiles, agricultural by-products and industrial crops.

The use of recycled fiber has been growing steadily since the 1980s. Between 40-50% of all paper used in North America is recovered for recycling and reuse. The recycling rate is higher in several European countries. (The recycling rate is calculated on the basis of recovered paper used in recycling compared to total paper consumption.)

The process of making paper has not fundamentally changed since its discovery. But, modern papermaking has evolved into a complex industry. The important steps in the production process are:

1. Forestry. Trees used for paper-making are usually grown and harvested like a crop. To meet future demand, forest products firms and private landowners plant millions of new seedlings every year.

2. Debarking, Chipping and/or Recycling. To begin the process, logs are first passed through a debarker, where the bark is removed. Next, the debarked logs are passed through chippers where the wood is cut into 1" pieces. The wood chips are then pressure-cooked in a digester with a mixture of water and chemicals. Used paper is an important source of paper fiber. The recycled paper is shredded and mixed with water.

3. Pulp Preparation. The pulp is washed, refined, cleaned and sometimes bleached, then turned to slush in the beater. Color dyes, coatings and other additives are mixed in, and the pulp slush is pumped onto a moving wire screen. Computerized sensors and state-of-the-art control equipment monitor each stage of the process.

4. Paper Formation. As the pulp travels down the screen, water is drained away and recycled. The resulting crude paper sheet, or web, is squeezed between large rollers to remove most of the remaining water and ensure smoothness and uniform thickness. The semi-dry web is then run through heated dryer rollers to remove the remaining water.

5. Paper Finishing. The finished paper is wound into large rolls, which can be 30 feet or more in width and weigh close to 25 tons. A slitter cuts the paper into smaller rolls and the paper is ready for use. Papermaking is a highly capital-intensive industry and, in many firms, there are over $100,000 in equipment for each employee. The largest paper-

making machines can be over 32 feet wide, 550 feet long and produce over 1,000 miles of paper a day.

3. Production Process and Investments: Categorization and Data

To develop our framework for analysis, we gathered information about the production process from various industry publications. In addition, both of us had visited pulp and paper mills in the U.S. and Northern Europe to get a first-hand look at the processes. Using this information, we classified the overall process into 15 key stages itemized in **Table 1**.

Next, as we looked through the important areas of operations of the pulp and paper firms, we created 4 broad categories in which we could observe important changes. These relate to (1) mechanical, (2) chemical, (3) monitoring devices and (4) information technology. We also created a fifth category "other" for those areas that do not fit into the four main categories noted above. Since each of the four main categories involve distinct processes and technologies, we classify them as "investment categories". The five categories are listed in columns 1 of **Table 2**.

Our insight is that by tracking firms' investments in equipment and machinery, chemicals and chemicals processes, monitoring devices and information technology, we obtain a broad sketch of the transactions the firms engage in. The main premise is that these investments allow firms to improve their productivity and competitive position relative to their rivals. The more active a firm is in making these improvements and upgrades, the more likely it is that the firm will improve its performance and productivity.

The pulp and paper industry is highly capital-intensive and uses machinery and equipment of various degrees of complexity in almost all of the processes outlined in table 1. As firms think of improving their performance and production efficiency, they can make new investments to modernize their production processes. Given the highly capital-intensive nature of production, a significant fraction of these investments are likely to fall under the "mechanical" category – related to investments in equipment and machinery. Chemicals constitute an important input into the paper-making process as they are used for processing woodchips, treating pulp, washing the pulp, coating paper, to name a few. Refinements in chemical inputs and chemical processes can lead to better paper, better coatings and may also reduce pollutants, leading to potentially lower environmental clean-up costs. Investments in monitoring devices and information technology have constituted important investments by many firms. Monitoring devices can help managers of firms exercise better control and timely intervention to check for problems in the production line, and help monitor quality of the outputs in the intermediate stages as well as the final product. Investments in information technology have become critical in various areas such as enterprise management, supply-chain management and integration of the monitoring devices into a centralized command structure.

Our next task was to gather information and gain insights into the transactions in each of the four key investment categories (noted in table 2) for the major firms in the global pulp and paper industry, and then provide a comparison of how the efforts to modernize and improve efficiency varied across the different firms. Unfortunately, due to confidentiality restrictions and lack of reliable and consistent firm-level data available in the public domain, this proved to be a far more difficult task than we had expected.

3.1. Compiling the Data

We examined information from a large number of pulp and paper industry resources. The publication *Pulp and Paper* was the only source that provided semblance of a consistent data source. For each of the investment categories noted in table 2, we collected information from *Pulp and Paper's* "Orders and Deliveries" section over the time-period 1996-2003. The time period for our data collection was restricted by the following: (1) at the time we started collecting the data, 2003 was the most recent year for which we could obtain complete data; and (2) the years before 1996 contained relatively sketchy data.

Included in the Orders and Deliveries information were names of buyers and suppliers, and some specifics of the transactions such as purchase of a new pulping or debarking unit, purchase or refurbishing of the paper mill, coating systems, calendaring machine, among many others. Table 2 (column 2) provides information on the range of transactions that were obtained by us. In terms of having a complete dataset, we have information on a total of 25 firms (buyers), including most of the major global firms. On the supplier side – that is, suppliers of equipment, machinery, chemicals, monitoring devices and information technology – our information contains names of over 20 firms (globally). We then developed a system of classification outlined in tables 1 and 2. We obtained information on firm-specific transactions under each of the 15 different processes noted in table 1, and then further classified them by the five investment categories described in table 2.

Before describing the features of these data, we provide a quick look at how we went about compiling the information. The buyer-seller transactions data were not available in machine-readable form. We had to first copy the relevant pages from the monthly issues of *Pulp and Paper* over the eight-year period, 1996-2003. Next we scanned the information, and then sorted, cleaned and systematized the information in machine readable form. After the data were in this more usable form, we then went through a painstaking process of examining each transaction, obtaining additional information on many of them from secondary sources such as the firms' websites, industry reports, among others, and then arranged them into the classification scheme outlined in tables 1 and 2. Across all the processes and categories under our two-tier (tables 1 and 2) classification system, we have a total of 462 buyer-seller transactions for the period 1996-2003 for 25 U.S. and foreign firms.

3.2. Pros and Cons of our "Orders and Deliveries" Investments Data

As we noted above, the *Pulp and Paper* publication is the only source we could find that reported such buyer-supplier transactions on a consistent basis. The other sources we were able to find were either very limited in scope and/or did not offer data on a consistent basis. The *Pulp and Paper* publication compiled information on the buyer-seller transactions as part of their own research as well as transactions reported to them by the firms on a voluntary basis.

There are two important shortcomings of the data. First, the data are not comprehensive in the sense that they do not contain data and information on all the transactions undertaken by a given firm over the 1996-2003 period. This deficiency is clearly a limitation, but there was no other source we could find that would allow us to obtain a complete set of transactions. Further, there were some firms for which we recorded zero or 1 transactions for the 8-year period. We tried to figure out the reason for the low counts, including contacting *Pulp and Paper*, and in some cases the firms, to see if we could fill in the gaps. This did not prove successful. Our requests made to the firms did not break this deadlock as they either did not have these data stored and available for distribution or there were issues related to confidentiality due to which the firms were not in a position to share the data with us. Much later, when we presented our initial findings at the TAPPI conference (Atlanta, Nov. 2006), the participants who were industry consultants and employees of paper firms mentioned that some firms do not make an effort to systematically store these types of data. To get a better feel for the missing data, we attempted to spot any obvious patterns, such as more or less missing transactions for U.S. versus foreign firms or smaller versus large firms. We were hard-pressed to identify any clear patterns in this dimension. Given these problems, we decided to drop these firms (with unrealistically low transactions over the eight-year period) from our sample. Dropping these resulted in a final set of 19 U.S. and foreign firms.

The second shortcoming is that while we were able to observe the transactions, we were not able to assess how large or small they were in monetary terms. It is clear that there are significant direct and indirect costs for transactions like machine rebuilds; the indirect costs arise due to work disruption, loss of output and other factors. But many of the transactions were related to upgrades in various stages of the production process, installation of monitoring devices, quality control devices, information technology adoption, among others. While these are clearly very important for the firms' attempts to modernize and upgrade production process with a view to improving their performance and competitive position, it would have been better if we also had a monetary sum to attach to these transactions. We return to this specific issue in our concluding remarks.

On the positive side, the information on the buyer-seller transactions for the categories listed in tables 1 and 2 are high quality and informative. To provide the reader with a glimpse of the richness of the data, below we present several examples to indicate the level of detail. Below we conceal some of the information including the "buying" company names and locations for confidentiality. Since the selling firms typically sell to many buyers, we do not conceal these names.

- [company name] has ordered a new complete Valmet uncoated free-sheet paper machine as part of a major expansion at its [mill name]. The new machine has a wire width of 380 in., a trim of 354 in., and is designed to run at 4,500 fpm and produce 910 tpd of office, offset printing, forms, and envelope papers containing varying amounts of virgin and recycled fiber.

- [company name] has installed a new Gardner Systems steam system with Blow-Thru controls on its paper machine dryer section. As a result of this installation, the machine has achieved higher production on heavier grades and has recorded steam savings that have averaged 15,000 pph.

- [company name] has ordered an enterprise software license agreement and long-term maintenance agreement form 3C Software for Impact:ECS, an enterprise cost management system. The implementation of Impact:ECS will being in Oct. 2002, at [company name] Fine Papers division in [location].

- [company name] purchased Industrial IT quality control and web imaging for coater machine.

- [company name] has named BetzDearborn the primary supplier of specialty chemicals at its [locations] paper mills. The three-year agreement covers chemicals used for water treatment and process systems.

- For its bleached kraft mill in [location], [company name] has ordered a two-line thickness screening system by Acrowood to install prior to its 10 batch digesters. Each of the two screening lines will include a disc scalper, two Model 50144 DiamondRoll primary thickness screens placed one after the other, a Model 7222 air density separator to process the overs before they are sent into a Model 3672 chip cracker, and a Model 90108 DiamondRoll fines screen fit with the raised roll feature to process fines.

- [company name] has nearly finished putting its 525-tpd recycled paperboard mill under full automation with new process control technology. The PlantWeb digital plant architecture from Emerson Process Management is superceding a Honeywell TDC3000 distributed control system.

- [company name] has ordered the world's largest basis weight actuator system from ABB Industrial Systems Inc. The [location] mill will install a Beloit Concept IV-MH headbox with dilution control provided by 277 zone AccuRay Smart Weight profiler-dilution actuators on paper machine No. 64. The project also includes the addition of Smart CD to the existing AccuRay 1180M system and measurement platform. [company name] has chosen Beloit for the management of its paper machine upgrade, including the integration and staging of the AccuRay profilers and Smart CD.

- [company name] has selected Brown & Root Engineering and Construction to provide construction services for environmental improvement projects at its [location] pulp and paper mills. The projects will convert the mills' bleaching sequences to elemental chlorine-free (ECF) and assure compliance with the EPA's cluster rules and [state] regulations.

- [company name] [location] mill has ordered a whitewater filtration system from AES Engineered Systems. The equipment includes AES's 4045 gravity strainer and multiple 14 station barrel pressure filter. [company name] will use the new equipment for straining and filtering whitewater from the mill's saveall clean leg for reuse on paper machine showers.

- [company name] has purchased its fifth digital break recording system from Papertech. The latest installation—a 12-camera system—is at [company name] [location] mill. Other installations include [company name]'s [locations] mills.

- [company name] has selected Rockwell Automation to implement a comprehensive power demand management system at its [location] paper mill. The Rockwell Automation Power and Energy Management Solution (PEMS) is designed to help eliminate plant-crippling power blackouts caused by fluctuations in power supply levels.

- [company name] has begun installation of Quantum Technologies' HiYield polysulfide pulping process at its [location] mill.

- [company name] has retained Sapient, a business and technology consultancy, to develop a proprietary, enterprise-wide solution for managing internal costs and providing customers online interactive design and project management tools. The system will provide performance measurement, operational, and order visibility capabilities.

- [company name] [locations] mills have agreed to receive their supply of precipitated calcium carbonate (PCC) from ECC/ Faxe LLC, a joint venture between English China Clays (ECC) and Faxe Paper Pigments. The new PCC plants will be located adjacent to the two paper mills and will produce PCC for both filling and coating applications.

These examples demonstrate the richness of the Orders and Deliveries transactions data from *Pulp and Paper* and allow us to take a close look at the operations of the firms.

In summary, while the incompleteness and lack of monetary values are shortcomings, we feel that the richness of the available data offered an unique opportunity to conduct research into the firms' efforts to modernize the production processes and business operations in order to improve their production efficiency and competitive position.

3.3. Investment Categories: Data Characteristics

Our examination of the orders and deliveries transactions data over the 1996-2003 period reveals wide variation in activity across the different U.S. and foreign firms in our sample. Our base data are compiled by the 15 process categories in table 1 and the 5 investment categories in table 2. For example, suppose we look at the process category # 3 "pulping" in table 1. In the pulping process, there are a variety of investments that can be made related to mechanical equipment, chemicals, monitoring devices, information technology, among others. That is, the 5 investment categories in table 2. Thus, we can think of classifications like 3A, 3B, 3C, 3D and 3E, with the numeric-ID corresponding to table 1 and the alphabetical-ID corresponding to table 2. Since our main interest is in the investment categories in table 2, and since presenting all the data would be rather tedious, in **Table 3** we present a summary by the investment categories. The following observations emerge from table 3.

First, as we look at the last column "Total" we note that there is significant variation across firms in the total number of transactions over the 1996-2003 period. The mean number of transactions are about 24 with the 25th and 75th percentile values being 13 and 34 transactions, respectively. The total number of transactions range from a low of only 4 to a high of 63. We observe five firms (#s 6, 14, 16, 18, 19) with roughly 40 or more transactions for the 8-year period. In contrast, there are four firms with less than 10 transactions for the same 8-year period.

Second, if we look at the row labeled "Mean" and examine the numbers corresponding to the columns, we note that the mechanical category (col. A) has the highest mean number of transactions at about 16. Information technology and monitoring devices are next at about 4.5 and 2.5 transactions. Thus, transactions (investments) in the mechanical category were the most important. The overall importance of the transactions in the mechanical category is not surprising given the highly complicated nature of the machinery being used in the pulp and paper production process and the frequent need to engage in maintenance, upgrading and modernization.

Third, if we examine the data within any category – mechanical, chemical, etc. – we see considerable variation across firms in the number of transactions. We took a closer look at the specific transactions in the mechanical category and found that there is significant variation across the firms in the extent of investment activity in the machine build/rebuild category. While many of the firms in our sample have little/no activity in this category, there are some firms with significant investments in this category over our sample period. Pulping is an important activity and the 1996-2003 period saw some firms engage in significant investments in this part of the production process whereas other firms made little or no investments and improvements. Finally, the processes related to draining water, squeezing and drying saw many firms incur significant investments.

Fourth, and this is not evident from the data presented in table 3, many of the recorded transactions were simultaneously in the categories of "monitoring devices" and "information technology", as well as some that occurred in combination with "mechanical". In part, this is due to the fact that installation of monitoring devices of various types (see table 2) – such as digital cameras and quality control devices – also involved investments in software and other information technology areas to provide a centralized control structure.

3.4. Investment Categories: Correlations

In **Table 4** we report the Spearman rank-order[6] correlations between the five investment categories. Transactions in the chemical area are not correlated with the other areas. This is probably not surprising given the relatively low number of transactions we recorded in the chemicals category. Transactions in the mechanical category are highly correlated with both monitoring devices and information technology. Finally, transactions in the monitoring devices category are highly correlated with information technology transactions. The latter observation reflects the fact that in many of the transactions we recorded, investments in monitoring devices went hand-in-hand with investments in software and other information technology areas. The strong correlation between mechanical and monitoring devices and information technology makes sense in that firms that installed newer equipment and production process often also installed the latest supporting devices and software for better control of intermediate and final products and the ability to intervene to correct for problems from their centralized control areas.

4. Firm-level Analysis

Our central objective is to link information on firm-level transactions in the various investment categories to some measure of firm-level performance. To focus our thoughts on this, consider the following general expression:

$$\text{(1)}\quad \text{Performance} = f(\text{Modernization Investments}; \text{Innovation Activity}; \text{Control Variables}).$$

[6] In Spearman's correlations, each variable under consideration is ordered by rank from low to high and then the rank-order correlation is computed.

All the variables in (1) are measured at the firm-level. We expect modernization and upgrading, as well as innovative activity, to deliver gains in performance. For measures of firm-level performance, we considered two candidates:

(1) Profitability. This is an obvious choice. But, as we note below, we encountered considerable difficulties in obtaining consistent and comparable data for the U.S. and foreign firms in our sample.

(2) Productivity. This is a meaningful measure of performance in the sense that firms that are more active in modernization investments, improving their production processes and engaging in innovative activity, should experience productivity gains compared to the firms that are less active. While there are several choices, we use "labor productivity" as our measure. The Compustat dataset did not allow us to calculate more sophisticated measures such as multi-factor productivity due to the lack of availability of data on materials usage, among other variables.[7]

Regarding the control variables, we considered three we felt were most important for our firm-level analysis:

(1) Mergers and Acquisitions (M&As). M&A activity was widespread in the industry during our sample period and M&As can significantly affect firms' productivity with the effects varying considerably in the shorter versus longer-run. M&As can be a source of technology acquisition (or, more generally, productivity gains), be motivated by reaping economies of scale and scope, act as a means of constraining capacity, among others, and, therefore, can significantly affect the performance of firms. Further, integration of newly-acquired firms can take time and drain the acquiring company of many resources. Acquiring firms may well see sharp drops in short-run productivity. If the takeover and

[7] See Ghosal (2003) for details on computing multi-factor productivity measures.

reorganization is successful, the acquiring firms may see gains in productivity over time. Some of the shorter versus longer run effects also depend on the pre-M&A differences in productivity between the acquiring firms and the target. In short, M&As are *ex-ante* an important control variable, although the sign of the relationship is uncertain due to the shorter and longer run issues noted above.

(2) R&D Expenditures and Patents. Firms' R&D expenditures and the number of patents granted are two commonly used measures of innovative activity. R&D can be thought of as an input measure of innovative activity whereas patents an output measure. Firms that have higher R&D and have more patents granted are expected to be more innovative and efficient compared to those that have lower propensities. We consider both of these not only as control variables, but also to examine whether innovative activity – in the sense of more R&D and patents – delivers gains in productivity. This question is interesting for a traditional industry like pulp and paper as firms in this industry typically have very low R&D intensities and, in general, have low patent counts.

(3) Capital-intensity. If we use labor productivity (that is, the ratio of total output to total labor) as our measure of performance, then capital-intensity, or the firm's capital-labor ratio, is an important control variable. This is because for a given amount of labor, firms that have a higher capital-stock will also produce more output resulting in higher labor productivity.

5. Firm-level Data

5.1. Sources

We collected firm-specific time-series data from several sources for the 10-year period 1995-2004. First, *Compustat North America* and *Global Vantage Database* provided firm-level information on sales, investment, capital-stock R&D expenditures, wages and other variables for the U.S. and foreign pulp and paper firms. Some of the data were incomplete and we attempted to fill the gaps from company 10K financial statements and other company publications such as annual reports. Data on R&D expenditures were much more difficult to obtain on a consistent basis. Our first attempt was to obtain the R&D data from Compustat. Unfortunately not all firms reported their R&D expenditures. Next, we examined various publications that had R&D data for major firms in each industry group. We also tried to fill in the gaps by examining the company 10K statements, annual reports and profit and loss statements of the firms in our study. When this did not succeed, we sent inquiries to the firms requesting R&D data. The response, unfortunately, was disappointing. Despite all these efforts, we still have fairly big gaps in our R&D data. Finally, we were unable to obtain meaningful data on firm-level earnings (or profits). The data presented in the Compustat contained large unexplained jumps in the data for several of the important firms in our sample. We examined ancillary data sources, including firms' 10K statements and annual reports but were unable to make sense of the large jumps. It almost seemed that the data definitions had changed or there was some change in reporting standards. Since we could not identify the cause, we decided to focus on productivity (described above) as our measure of performance.[8]

[8] The firms for which there were large jumps in the data were significant players in the market and dropping them from the sample would make little sense.

Second, we used the *U.S. Patent Office* and the *European Patent Office* databases by searching for patents awarded each year to each U.S. and foreign firm in our sample. These two databases cover the majority of the patents awarded globally. We combined all the patents issued to a firm and its subsidiaries.

Overall, while we were able to get a reasonably complete dataset on the number of patents granted to firms in the pulp and paper industry, the data on R&D expenditures are somewhat incomplete (i.e., have missing observations).

Third, the *Thompson Financial* database provided us with the Mergers and Acquisitions data. The database is in text form and had to be converted using XML programming into a format suitable for our purposes. The difficulty and complexity of working with this database resulted in a very time-intensive effort and also involved extensive consultations with the database provider. The M&A data are often at the subsidiary-level rather than the parent-firm-level. Therefore, we had to collect information about each firm's subsidiaries, obtain M&A data on each firm and its subsidiaries, and combine the data to get the overall firm-level M&A activity in order to make this data compatible with the Compustat database we described above.

Compiling all of the above data and integrating them in a useable format has given us a unique database. This adds significant value to our project. To the best of our knowledge these data are being systematically compiled for the first time.

5.2. Summary Statistics

Table 5 presents information on the data sources and some description. **Table 6** presents the summary statistics for selected firm-level variables for our final set of 19 firms that we use for our regression analysis. The 19 firms are those for which we have complete data from the

Pulp and Paper investment categories (table 2) as well as firm-level data from the Compustat, Thompson Financial, and U.S. and European patent offices. Some observations that emerge from table 6 are as follows.

- For the typical firm in our sample, the average level of capital stock over this period was \$8,682 million per year. The range, as defined by the spread between the 25th and 75th percentile, is \$2,533 million to \$14,392 million. This shows that the firms in our sample vary considerably in size, as defined by their stock of capital.
- The rate of (new) investment is defined as the ratio (INV_t / CAP_{t-1}), which is current year total investment in plant, equipment and machinery divided by the previous year's stock of capital. This ratio gives us the net (or new) investment in the current year. For the typical company in our sample, the mean rate of new investment was 6.3% per year over the 10-year period. The rate of investment over this period varied a good deal among firms, ranging from 4.8% (25th percentile) to 7.6% (75th percentile). A part of the variability in investment and capital stock can be attributed to M&As with the investment of the merged firm increasing substantially in the post-merger year.
- The mean growth in sales shows fairly large differences across the firms with the 25th percentile value being 3.8% per year for the 10-year period versus the 75th percentile value of 9.9% per year.
- Productivity is a key variable in our analysis. For the typical firm in our sample, the mean level of labor-productivity is \$166.56 thousand dollars per employee. The gap between firms seems quite important as it ranges from \$147.7 thousand dollars per employee (25th percentile) to \$202.15 thousand dollars per employee (75th percentile). While this may not seem such a striking difference, modest differences in productivity being sustained

over time can mean marked differences in the competitive position of firms in the longer-run.

- The mean value of R&D intensity, as measured by the ratio of R&D expenditures to sales, is about 0.6%. This is quite low. Even at the 75th percentile value of 0.7%, the R&D intensity seems fairly low.[9]
- The typical firm in our sample had a total of 1,024 patents granted. In contrast to the R&D data, what is striking about the patent data are the dramatic differences between firms. At the 25th percentile value, the firm has a total of 6 patents for the 10 year period, whereas at the 75th percentile value the firm has 254 patents. As we examined the underlying data about company specifics and patents, some of these differences are arising due to the different range of products being manufactured by the firms in our sample. Even so, the differences between the range of R&D intensities and the patent counts seems quite striking.[10]
- In terms of the total number of M&As over the 10-year sample period, the range is between 10 (25th percentile) to 19 (75th percentile). As we look at the disaggregation by domestic versus foreign mergers, we observe that the range is quite large for both types. One reason why the range is larger for the disaggregated components (domestic and foreign) as opposed to the totals is that some firms show more activity in the foreign M&As category versus the domestic and vice versa.

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[9] As a comparison, for the year 2004, Proctor and Gamble had an R&D intensity of about 4% and Microsoft Corp. of about 21%.

[10] While table 6 presents data on the final set of firms we use for our regression analysis, our complete dataset contained quite a few more firms. As we looked closer at the patents data we found that of the 51 firms we have data for, 34 firms had patents ranging from 0 to 15 over the period 1995-2004. Of these, 11 had no patents. There were 10 firms each with a total of more than 100 patents during this time period. And one firm accounted for 6483 patents out of a total of 11935.

Overall, the data on our final set of firms shows fairly significant variation across the firms and this is encouraging from the viewpoint of our proposed regression analysis to estimate the linkages between modernization and upgrading investments, innovative activity and productivity.

5.3. Correlations between Firm-Specific Variables

For selected variables of interest, we examined the Spearman rank-order correlations between the firm-level data we compiled from the Compustat, Thompson's Financial and the U.S. and European Patent offices. The correlations are unconditional pairwise-correlations and do not control for the influences of other variables – this is in contrast to the regression analysis where we have other control variables.

- Productivity shows a strong positive correlation with: (a) firm-size (as measured by capital-stock or sales) with the correlations being in the 0.5 to 0.6 range; and (b) capital-intensity as measured by the capital-labor ratio, with the correlation being about 0.7.[11] The latter is expected as, for a given amount of labor, the higher is the capital-stock, the higher will be the firm's production. The former is interesting in the sense that there is no unambiguous *ex-ante* prediction from theory between firm-size and productivity. But in

[11] For (K/L), which we use in our cross-firm productivity analysis, our data on K is nominal and L (the number of employees) is, of course, real. This causes an error in the (K/L) data as both K and L should be in real values. We did not convert K to real as we did not have data on a capital price deflator. On the plus side, if we reasonably assumed that firms in the industry faced roughly similar capital costs (at least in Europe, Canada and the U.S.) on the assumption that they are drawing on the same international capital markets to finance their physical capital purchases, then the deflator would be roughly common for all firms. In this sense, while the numbers on K are inflated due to using nominal values, using a common deflator across all firms would scale-down the K values uniformly across all firms. Thus, the ranking of mean (K/L) values across firms would not change. Of course, if capital price data are available at the firm level, they can be used to obtain the correct real values of K and construct (K/L) accordingly.

our sample of pulp and paper firms, there appears to be a fairly strong positive correlation.

- Total number of patents granted over the 10-year sample period is: (a) positively correlated with firm-size as measured by sales or capital stock with the correlation being about 0.5; (b) positively correlated with firm-level R&D intensity with a correlation of 0.4; and (c) weakly correlated with labor productivity with a correlation of 0.3. All of these correlations are generally in the expected directions. Larger firms typically have more resources to devote to innovative activities and therefore the link to larger number of patents is not unexpected.
- M&As, total, domestic and foreign, are: (a) negatively correlated with capital-intensity with the correlations ranging from about -0.4 to -0.7; and (b) negatively correlated with productivity with correlations ranging from -0.2 to -0.5. Foreign M&As are positively correlated with firm-size, R&D and patents with the correlation being in the range 0.4 to 0.6.

5.4. Correlations between Investments and Firm-Specific Variables

These correlations are reported in **Table 7**. The correlations are unconditional pairwise-correlations and do not control for the influences of other variables. The following observations emerge:

- Firm-size, as measured by capital-stock, is positively correlated with the transactions in all of our investment categories noted in table 2. This indicates that larger firms on average are more active in making new investments related to upgrading, maintenance and modernization.

- Productivity has a meaningful positive correlation with transactions in the mechanical, monitoring devices and information technology categories. This is encouraging as it indicates that attempts to upgrade production processes and engage in modernization is likely to be paying off in higher labor productivity.
- Total patent counts, like productivity, have a positive correlation with transactions in the mechanical, monitoring devices and information technology categories.
- R&D is generally negatively correlated with the transactions in our investment categories. This, in part, may reflect the fact that the R&D data were particularly unreliable and had missing observations for many firms.
- Sales growth is not correlated with any of the investment categories. This is somewhat disappointing as one would have liked to see that improvements in production processes and efficiency would lead to improved market position and sales growth.

While the correlations in table 7 are unconditional correlations, they show some interesting relationships between the investment variables and the firm-specific variables. Our regression analysis will shed a bit more formal light on this issue.

6. Regression Analysis: Baseline Results

Earlier, in expression (1), we had outlined our general approach. In this section we outline the baseline regression specification and results. Our baseline estimates do not include the investment categories variables.

Consider a standard Cobb-Douglas production function:

(2) $q_i = A_i L_i^{\alpha} K_i^{\beta}$,

where "i" denotes the firm subscript, A is an index of the firm's technology, q, L and K are the firm's output, employment and capital stock, and α and β are the coefficients related to the shares of labor and capital in production. For simplicity, we assume (α+β)=1, or constant returns-to-scale. Dividing equation (2) throughout by L, and using β=(1-α) from above we get:

$$(3)\ \left(\frac{q}{L}\right)_i = A_i\left(\frac{K}{L}\right)_i^{1-\alpha}.$$

The dependent variable is the firm's labor productivity. Expressing (3) in logarithms, we get a log-linear specification:

$$(4)\ \ell n\left(\frac{q}{L}\right)_i = \ell n A_i + (1-\alpha)\ell n\left(\frac{K}{L}\right)_i$$

In this section, we present estimates from specification (4) as well as by augmenting it with variables related to the number of patents and mergers and acquisition; we discussed both these variables in section 4. The augmented specification is given by:

$$(5)\ \ell n\left(\frac{q}{L}\right)_i = \ell n A_i + (1-\alpha)\ell n\left(\frac{K}{L}\right)_i + \delta Patents_i + \lambda Mergers_i + \varepsilon_i,$$

where δ and λ are the coefficients and ε_i is the regression error. The two variables "Patents" and "Mergers" are <u>not</u> in logarithmic form as there are some firms in our sample with zero values for these variables. The specification we estimate is, therefore, in *semi-logarithmic* form.

In terms of measurement of the variables, the productivity term (q/L) is the mean labor productivity for the 10-year period 1995-2004, (K/L) is the mean capital-labor ratio for the 10-year period, and Patents and Mergers are the total number of patents and mergers and acquisitions over the 10-year period. While the complete specification includes all of the above variables, we also present results with subsets of the variables. These results are presented in **Table 8**. The key observations that emerge are:

- As expected, a firm with higher capital-labor ratio has higher labor productivity with the estimated coefficients being highly statistically significant in all the specifications.
- Firms with a larger number of patents show greater labor productivity. The estimated coefficients are highly significant. This result is in the expected direction.
- The number of M&As a firm engaged in – one of our control variables – appears not to be important in explaining differences in labor productivity across firms. We included this control variable because firms that are more active in M&As may face uncertain shorter and longer-run outcomes due to the uncertainties of integrating the new acquisitions. Our data do not reveal a significant relationship in either direction.
- The regression adjusted-R^2s are between 0.66-0.68 implying that about two-thirds of the (logarithm of) labor productivity differences across firms are explained by the variables included in the estimated specification.

In an ancillary regression we included R&D intensity as a control variable. To include R&D, we had to drop a few firms from our sample of 19 firms due to the lack of R&D data. R&D turned out to be insignificant in all the estimated specifications. This is likely due to the data problems we noted earlier. Given this result, we do not focus on R&D in our subsequent analysis.

7. Regression Analysis: Incorporating the Investment Categories

In this section we augment the baseline specification (5) to include our investment categories variables. The central objective is to examine the linkages between the firms' transactions in the various investments and performance, which in our case is productivity. The augmented regression takes the form:

$$(6)\ \ell n\left(\frac{q}{L}\right)_i = \ell n A_i + (1-\alpha)\ell n\left(\frac{K}{L}\right)_i + \delta Patents_i + \lambda Mergers_i + \phi Investments_i + \nu_i,$$

where υ_i is the regression error term and "Investments" refers to mechanical, monitoring devices, information technology and chemical classifications described in table 2. As with the data on patents and mergers, there are some firms that have observations of zero for some of the investment categories. Therefore, investments are not entered in logarithmic form. We first use the total number of transactions across all categories to get a broad picture. Then we re-estimate (6) by using the individual investment categories to provide a comparison of the effects of the transactions in the different categories.

The estimates appear in **Table 9**. First, we examine the estimates presented in columns A-D; in these columns, we include the total number of M&As as a control variable. The observations that emerge from table 9 (columns A-D) can be summarized as follows:

- The estimate of the total number of investment transactions (column A) is positive and highly significant, indicating that firms that engaged in a larger number of transactions typically had higher labor productivity.

- When we disaggregate the total into the mechanical and digital[12] components, we find that the estimates of both categories are highly significant indicating that these transactions individually played an important role in enhancing productivity. The point estimate of the digital transactions is greater than the mechanical category, but, as we evaluate later, the estimated quantitative effect of the digital category is only slightly larger than mechanical.
- The estimate of the chemicals category while positive, is statistically insignificant. This is probably not too surprising given that we do not observe many transactions in the chemicals category for our sample of firms.
- If we compare column F in table 8 to column A in table 9, the latter has an adjusted-R^2 that is 0.135 greater. Thus, adding just one variable – the total number of investment transactions – increases the (degrees of freedom adjusted) explanatory power by 13.5%; a fairly meaningful increase.
- Given our small sample, we have some concerns about the degrees of freedom. Since the M&A effects were statistically insignificant, we re-estimated specification (6) by excluding the M&A control variable. These estimates are presented in columns E-H of table 9. Our broad inferences remain intact.

To summarize, the investment transactions aimed at modernization and upgrading of the production processes and other aspects of firm operations do seem to be an important factor explaining productivity differences across firms in the pulp and paper industry. In particular, firms that engaged in a larger number of transactions in the monitoring devices and information technology areas seem to have experienced a noticeable boost in productivity.

[12] As we note in the table, the “digital” category is the sum of the “monitoring devices” and “information technology” categories.

7.1. Assessing the Quantitative Impacts

While the estimates in table 9 inform us of the sign (direction) and statistical significance of the relationship, they do not provide a clear picture of the implied quantitative effects. If we consider the coefficient estimates in column A of table 9 and the functional form in equation (6), the equation for the logarithm of labor productivity can be written as (we drop the subscripts for convenience):

$$(7)\ \ell n\left(\frac{q}{L}\right) = 3.3557 + 0.3394\ell n\left(\frac{K}{L}\right) + 0.000016\text{Patents} - 0.0024\text{Mergers} + 0.0056(\text{TI : Total}).$$

Suppose we consider evaluating the quantitative effect of TI:Digital on (q/L). We start by assuming that both variables – (q/L) and TI:Digital – are initially at their sample means (see table 3 and table 6). Next, we consider a one-standard-deviation increase in TI:Digital. Considering a one-standard-deviation change (increase) is reasonable as this number is arising from the distribution of observed numbers from within the set of firms in our sample. This procedure then allows us to examine by how much would (q/L) change following the one-standard-deviation change in TI:Digital. Similarly for all the other variables.

Table 10 presents the estimated quantitative effects. The estimates indicate that the largest increase in (labor) productivity comes from increase in the firm's capital-labor ratio. This is expected as, *ceteris paribus*, a higher capital-to-labor ratio is at the core of a pulp and paper firm's ability to produce more. Given the units of measuring productivity, the quantitative estimates in table 10 show that a firm that has a one-standard-deviation higher (K/L) has approximately $26,970 higher (labor) productivity.

The next largest set of increases in productivity come from the number of transactions a firm engaged in the mechanical and digital categories, with transactions in the digital category providing a slightly larger quantitative boost to productivity. Given the units of measuring productivity, the quantitative estimates in table 10 show that a firm that has a one-standard-deviation larger number of transactions in the mechanical and digital categories has approximately $13,450 and $15,520 higher (labor) productivity, respectively.

The chemicals category does not provide a boost given that the point estimate from table 9 is statistically insignificant. As noted in table 9, the point estimate of M&As was also statistically insignificant, implying that M&As do not impact productivity in our sample of firms.

Finally, we used patents as a measure of pure innovation output and our quantitative estimates in table 10 show that the gains to productivity from higher patenting is positive – accounting for about $6,000 to $9,000 increase in productivity. The quantitative effect of patents are lower than that those obtained from the transactions in the mechanical and digital technology categories.

8. Some Implications of our Findings

Our study was motivated by the changing landscape in the pulp and paper industry as well as our observations from trips to various pulp and paper mills where we obtained an in-depth understanding of the economic realities and how the firms were responding to improve their competitive position. Based on observation-based insights from visits to pulp and paper mills, Ghosal (2003) noted that various kinds of "incremental" innovations, modernization investments, among others, appeared to be the mainstay of how firms in the pulp and paper industry viewed themselves as staying competitive in the short-run as well as gaining on their competitors in the longer-run.[13] Breakthrough innovations that characterize some industries are not the most important factors that drive the changing competitive position and performance of firms in this industry. In contrast, firms that succeed in implementing even small gains in productivity on a year-to-year basis via investments in upgrading and modernization, as well as making changes to the supply-chain, would in the medium-to-longer run gain relative to those firms who were not successful at implementing such strategies.

The results in this paper, linking productivity differences across firms to modernization investments and upgrading in various categories, as well as examining the link to patents, appear to strongly reinforce this message. Patents, for example, help explain differences in productivity across firms, but the quantitative effect is not very large. In contrast, the estimated impact of investments in the mechanical, monitoring devices and information technology categories on productivity is positive and larger than those observed for patents. Based on our results, R&D expenditures do not make a meaningful contribution to productivity. The clear message is that firms need to stay focused and actively implement modernization investments in all stages of the production process to ensure that they achieve gains in productivity. Further, while these investments may only produce relatively small gains in productivity on a year-to-year basis, it is important to recognize that these small gains can compound over time to form larger differences in productivity across firms in the longer-run. To provide an illustrative display, consider two firms A and B starting off at our sample mean level of productivity of $166,562 (see table 6). Now assume that firm A implements various modernization investments and other strategies and experiences an annual average growth in productivity of 1.8%; a number noted in Ghosal (2003) based on visits to pulp and paper mills. In contrast, let firm B achieve a lower 1.25%. **Figure 1**

[13] Norberg-Bohm et al. (1998) present insights on specific aspects of incremental innovations in this industry.

plots the illustrative time-paths of the evolution of productivity starting at year 1 when both are equal. **Figure 2** plots the percentage gap in productivity between firms A and B. In year 1 the productivity gap is zero by construction. The productivity gap increases to 5% in year 10. The relatively small annual difference compounds to form a noticeable productivity gap between the two competitors. In an industry where profit-margins have tightened considerably due to changing global market conditions, such a productivity gap can make a meaningful impact on profitability and a firm's competitive position.

9. Concluding Remarks

The primary contributions of this paper can be viewed as follows. First, we develop a framework within which we conceptualize firms' operations and strategies to boost productivity. We did not emphasize much of the standard literature that focuses on R&D expenditures and patent counts to gauge firms' innovation activities and link these to the measures of performance. While R&D and patents are useful measures in many industries, in general they are unlikely to be good measures for firms in the pulp and paper industry. This is because firms in this industry typically have a rather low R&D intensity, as measured by the ratio of R&D expenditures to sales, and most firms do not hold a large number of patents. Our prior, therefore, was that R&D and patents were unlikely to be the key channels. Our empirical results confirm this insight. We found that patents had a relatively small positive contribution towards firm-level productivity and our experiments with R&D revealed that it was not a factor in boosting productivity. Our visits to various pulp and paper mills convinced us that examining investments made by firms related to modernization and upgrading would be more useful in gaining insights. In short, the framework we adopted was more expansive, allowing alternative channels to affect firm-level productivity.

Second, we compiled an extensive dataset from diverse sources. These were described in detail in sections 3 and 5. As far as we are aware, there is no other study of firms in this industry which has put together such a diverse amount of data and information to analyze issues related to investments, innovation, M&As and productivity.

In combination, we feel that our framework and the data we have collected can serve as a useful starting point for future research on productivity and performance issues not only for firms in the pulp and paper industry, but also provide a useful model for research for other industries.

We noted several shortcomings of our data. Our hope is that future research can fill the gaps in the data and provide a more comprehensive picture. There are three areas in particular where additional data and insights would add value to this line of research. The first one relates to quantifying the monetary value of the investments in the mechanical, chemicals, monitoring devices and information technology categories. Despite our best efforts, we were unable to put together a reasonable dataset in this dimension. If one is able to attach monetary values, then one could provide useful insights on prioritizing the different areas of investments and modernization. The second one relates to obtaining a consistent database for firm-level profits. Profits are a key measure of firms' bottom-line and would serve as an important complement to examining productivity differentials across firms. Due to the reasons noted in section 5.1, we were unable to compile a consistent and comparable data on U.S. and foreign firms in the pulp and paper industry. Third, despite our best efforts, we were unable top put together a sample with a larger number of firms. This was due to the diverse nature of the data we had to compile and the myriad sources. Future research, by compiling information on a larger number of firms, may provide additional insights.

Apart from the path we pursued in this paper, there are two areas of research that can yield valuable insights. First, would be to examine the organizational and management changes the firms in the pulp and paper industry made in response to the competitive challenges. Following up on visits to pulp and paper mills, Ghosal (2003) presents an observation-based analysis which indicates that firms made dramatic modifications to their organizational structure and supply-chain to achieve gains in productivity. An examination of organizational and management changes in combination with our data-driven analysis will provide a more encompassing picture of business strategies pursued by firms in the pulp and paper industry.

Second, our discussions with firms' production managers, other executives and industry analysts revealed that while R&D as traditionally measured is low, the typical worker in a pulp and paper firm can be quite technical – for example, many of them are mechanical and chemical engineers – and these employees contribute to learning-by-doing gains in productivity, pointing out areas that need upgrading and modernization and various forms of incremental innovation. While these employees are hired to do routine work for the firm, they also contribute as "R&D workers" at the margin. Unfortunately, our initial efforts to put a number on this dimension proved unsuccessful and we hope to pursue this in our ongoing research.

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Table 1
Production Process

Process Number	Process Description
1	Debarking
2	Chipping
3	Pulping (pressure-cooking)
4	Washing
5	Refining
6	Cleaning
7	Bleaching
8	Dying
9	Coating
10	Pumping
11	Draining Water
12	Squeezing (removing water)
13	Drying
14	Calendaring
15	Slitting

Table 2
Investment Categories

Category	Comments
Mechanical	Transactions in this category include major machine rebuilds and a variety of other investments, upgrades and modernization of physical equipment related to the processes described in table 1. The recorded transactions in this category include a wide range such as press section rebuilds, installation of fibreflow drum pulper, coating systems, new recovery boiler, paper winders, screening systems to remove plastics and contaminants, replacement of chip-and-saw heads with turnknife chipping heads, covers for supercalender, gravity strainers and showers, steam systems with blow-thru controls on paper machine dryer sections, pre-evaporation systems to capture blow steam from mill pulping process, chip thickness screening equipment, sludge dewatering equipment, among many others.
Chemical	Includes transactions related to dyes, pigments, water treatment chemicals, among others. Some examples include high yield polysulfide pulping processes and precipitated calcium carbonate for coating and filling. Chemicals are an important component of the process categories 3-9 in table 1.
Monitoring Devices	Included in this category are transactions related to digital cameras and a variety of other devices designed to monitor the production line. Examples include devices that monitor fluid leaks in the production line, paper jams, paper quality, paper reflection, paper-coat weight, curl and moisture on the coater, digital break recording systems, devronizer systems and on-line measurement of kappa and dissolved lignin.
Information Technology	Transactions in this group included purchase and installation of new software and integration investments with digital devices and other aspects of production. Examples include integrated quality control systems to provide regulatory control for paper machines, order fulfillment systems, wood procurement systems, transportation management and plantwide information systems.
Other	Miscellaneous transactions not covered in the above categories. Examples include construction services for environmental improvements, contracts to manage wastewater treatment facility, injury prevention initiatives and initiatives to reduce water consumption.

1. For some of our analysis we will combine “Monitoring Devices” and “Information Technology” into one category labeled “Digital” as several of the transactions we recorded contained elements of both.

Table 3
Investment Categories: Data Summary
Time period: 1995-2003

Firm ID	Mechanical	Chemical	Monitoring Devices	Information Technology	Other	Total
1	9	0	3	5	0	17
2	16	1	1	2	0	20
3	2	0	1	1	0	4
4	11	0	2	3	0	16
5	5	1	1	1	0	8
6	44	1	5	10	3	63
7	16	1	3	5	0	25
8	8	1	3	3	0	15
9	10	0	2	4	0	16
10	13	1	2	5	3	24
11	3	0	0	1	1	5
12	22	0	3	4	0	29
13	4	1	1	1	0	7
14	33	0	3	5	2	43
15	17	0	1	2	1	21
16	31	0	3	8	0	42
17	4	0	3	5	0	12
18	26	0	6	13	2	47
19	31	0	2	5	1	39
Mean	16.05	0.37	2.36	4.37	0.68	23.84
Std. Deviation	12.05	0.49	1.46	3.18	1.06	16.19
25th Percentile	6.50	0.00	1.00	2.00	0.00	13.50
50th Percentile	13.00	0.00	2.00	4.00	0.00	20.00
75th Percentile	24.00	1.00	3.00	5.00	1.00	34.00

1. The table presents summary statistics for our final set of 19 firms that we use for our regression analysis.
2. The numbers represent the totals over the sample period. For example, for firm #6, the total number of recorded transactions was 63, with 44 of those being in the “mechanical” category, 10 in the “information technology” category, etc.

Table 4
Correlation between Investment Categories

	Mechanical	Chemical	Monitoring Devices	Information Technology	Other	Total
Mechanical	1.000	_	_	_	_	_
Chemical	-0.069	1.000	_	_	_	_
Monitoring Devices	0.558	-0.072	1.000	_	_	_
Information Technology	0.700	-0.142	0.871	1.000	_	_
Other	0.507	-0.011	0.178	0.414	1.000	_
Total	0.969	-0.059	0.691	0.825	0.543	1.000

1. The reported numbers are the Spearman rank-order correlation coefficients.

Table 5
Description of Firm-Specific Variables

Variable Name	Variable Description
Capital Stock	Source: Compustat. Net book value of physical capital: sum of plant, equipment and machinery. This is measured in nominal (current) dollars (in millions) as no price deflator for physical capital was available.
New Investment	Source: Compustat. Ratio of "net current year expenditures on plant, equipment and machinery" to previous year's "net capital stock". This gives us the rate of new investment in the current year.
Capital-labor ratio: (K/L)	Source: Compustat. Ratio of "net current year capital stock" to "current year employment". This measures the capital-intensity. Capital stock is measured in $ millions and # employees is measured in thousands.
Total Sales	Source: Compustat. Real sales or the ratio of "current dollar value of total sales" to "industry product price deflator". Since we did not have access to firm-specific product prices, we could not use an industry deflator. "Sales Growth" is the percentage annual growth of real sales. Sales is measured in $ millions.
Productivity	Source: Compustat. Ratio of "real sales" to "employment". This gives us the labor productivity as measured by sales per worker. Sales is measured in $ millions and employees in thousands. Since no output (or production) data were available, we did not construct an output based productivity measure. "Productivity Growth" is the percentage annual growth of productivity.
R&D	Source: Compustat and other publications. Ratio of "current dollar expenditures on research and development" to "current dollar value of sales". This gives us the R&D intensity.
Patents	Source: U.S. and European Patent Offices. Total number of patents granted.
M&A: Total	Source: Thompson's Financial. Total number of M&As, domestic and foreign.
M&A: Domestic	Source: Thompson's Financial. Number of M&As where the target was domestic or within the country.
M&A: Foreign	Source: Thompson's Financial. Number of M&As where the target was foreign or outside the country.

1. All raw data are at an annual frequency for the years 1995-2004.

Table 6
Firm-Specific Variables: Summary Statistics

	Mean	Std. Deviation	25th Percentile	50th Percentile	75th Percentile
1. Capital Stock (Nominal $ millions)	8,682.694	8,480.563	2,533.352	5,538.300	14,392.262
2. New Investment (Percent)	0.063	0.022	0.048	0.057	0.076
3. (K/L) ($ '000 per worker)	135.721	64.751	82.969	146.604	175.411
4. Total Sales (Real $ millions)	5,511.040	5,561.422	1,260.080	2,732.206	9,587.847
5. Sales Growth (Percent)	0.067	0.046	0.038	0.0695	0.099
6. Productivity ($'000 per worker)	166.562	39.577	147.704	162.504	202.150
7. R&D (Percent)	0.006	0.005	0.003	0.004	0.007
8. Patents (Total number)	1,024.211	3,384.972	6.000	20.000	254.500
9. Mergers: Total (Total number)	16.632	13.635	10.000	14.000	19.000
10. Mergers: Domestic (Total number)	9.158	6.817	1.500	11.000	13.000
11. Mergers: Foreign (Total number)	7.474	9.330	1.000	4.000	9.000

1. The table presents summary statistics for selected firm-level variables for our final set of 19 firms we use for our regression analysis.
2. For variables in rows 1-7 above, the raw data are at an annual frequency. For each variable we computed the 10-year (1995-2004) **mean**. We get 19 mean values corresponding to the 19 firms. The numbers above are the cross-firm summary statistics corresponding to these mean values. E.g., the 10-year mean rate of new investment (row 2) across the 19 firms was 6.3% with a standard deviation of 2.2%.
3. For variables in rows 8-11, the raw data are at an annual frequency. For each variable we computed the 10-year **total**. The numbers reported are the cross-firm summary statistics corresponding to these totals. E.g., the total number of M&As (row 9) averaged 16.63 with a s.d. of 13.63.
4. The sales and capital-stock numbers are not comparable as the former in real dollars and the latter in nominal (see table 5).

Table 7
Correlation between Investment Categories and Selected Firm-Specific Variables

	Orders and Deliveries Investment Categories				
	Mechanical	Chemical	Monitoring Devices	Information Technology	Total
Capital Stock	0.387	0.259	0.654	0.725	0.508
Sales Growth	-0.004	0.139	0.105	0.061	0.035
Productivity	0.270	0.119	0.363	0.549	0.347
R&D	-0.309	0.454	-0.299	-0.293	-0.319
Patents	0.273	0.149	0.569	0.459	0.356

1. The data on the investment categories are as noted in table 3. And the data on the firm-specific variables are as noted in tables 5 and 6.
2. The reported numbers are the Spearman rank-order correlation coefficients.

Table 8
Regression Results I

Specification (5): $\ell n\left(\frac{q}{L}\right)_i = \ell nA_i + (1-\alpha)\ell n\left(\frac{K}{L}\right)_i + \delta Patents_i + \lambda Mergers_i + \varepsilon_i$.

	A	**B**	**C**	**D**	**E**	**F**
1. Intercept	3.3512* (20.38)	3.2512* (17.13)	3.3061* (14.36)	3.2897* (19.22)	3.2901* (22.39)	3.3130* (17.68)
2. *ln*(K/L)	0.3634* (10.50)	0.3796* (10.45)	0.3708* (9.01)	0.3732* (10.91)	0.3740* (11.68)	0.3703* (10.70)
3. Patents	–	–	–	–	0.000011* (2.62)	0.000011* (2.05)
4. Mergers: Total	–	0.0013 (0.71)	–	–	–	-0.00036 (-0.17)
5. Mergers: Domestic	–	–	0.0011 (0.21)	–	–	–
6. Mergers: Foreign	–	–	–	0.0019 (0.81)	–	–
# Observations	19	19	19	19	19	19
Adjusted-R^2	0.6806	0.6652	0.6613	0.6661	0.6824	0.6614

1. As noted in section 6, patents and mergers are not measured in logarithms.
2. *t-statistics* computed from heteroscedasticity-consistent standard-errors are in parentheses. An asterisk * denotes statistical significance at least at the 10% level.
3. In ancillary specifications we experimented with using firm-level R&D as an alternative measure of innovative activity. None of the R&D coefficients were significant, hence we do not report them here.

Table 9
Regression Results II

Specification (6): $\ell n\left(\frac{q}{L}\right)_i = \ell nA_i + (1-\alpha)\ell n\left(\frac{K}{L}\right)_i + \delta Patents_i + \lambda Mergers_i + \phi(Targeted\ Investments)_i + \nu_i$.

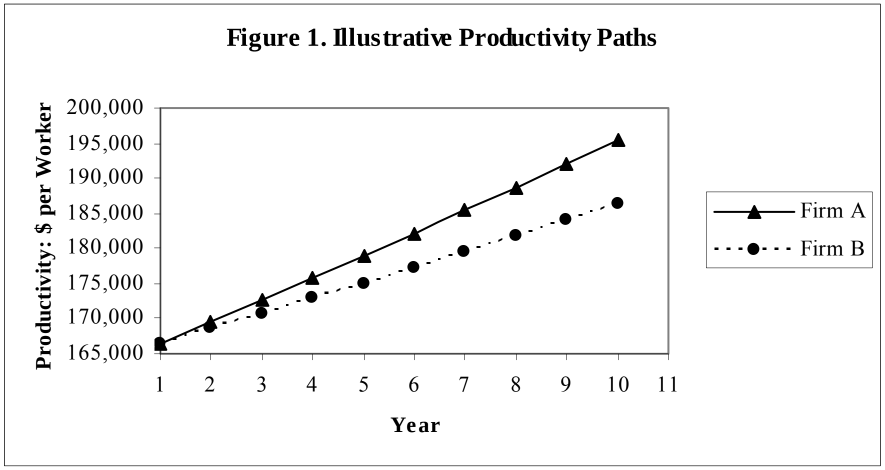
	Include Control for Mergers				Exclude Control for Mergers			
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1. Intercept	3.3557* (15.28)	3.3235* (15.53)	3.3932* (15.02)	3.3442* (16.78)	3.2105* (22.54)	3.1885* (22.97)	3.3148* (20.78)	3.3038* (21.94)
2. *ln*(K/L)	0.3394* (8.01)	0.3507* (8.33)	0.3279* (7.17)	0.3614* (8.79)	0.3642* (11.48)	0.3735* (11.93)	0.3408* (9.49)	0.3680* (10.05)
3. Patents	0.000016* (3.18)	0.000017* (2.90)	0.000011* (2.78)	0.000009 (1.45)	0.000011* (4.25)	0.000012* (3.94)	0.000008* (3.68)	0.000008 (1.43)
4. Mergers: Total	-0.0024 (-1.03)	-0.0022 (-0.90)	-0.0012 (-0.65)	-0.0006 (0.33)	–	–	–	–
5. TI: Total	**0.0056*** (3.98)	–	–	–	**0.0053*** (3.28)	–	–	–
6. TI: Mechanical	–	**0.0067*** (2.82)	–	–	–	**0.0064*** (2.44)	–	–
7. TI: Digital	–	–	**0.0204*** (4.09)	–	–	–	**0.0202*** (4.12)	–
8. TI: Chemical	–	–	–	**0.0492** (0.65)	–	–	–	**0.0476** (0.63)
# Observations Adjusted-R^2	19 0.7961	19 0.7657	19 0.8072	19 0.6476	19 0.7996	19 0.7724	19 0.8172	19 0.6704

1. As noted in sections 6 and 7, patents, mergers and investments are not measured in logarithms.
2. TI's represent the "targeted investment" variables. TI:Mechanical, for example, are the targeted investments in the mechanical category.
3. The "TI: Digital" category in row 5 is the sum of the "Monitoring Devices" and "Information Technology" categories noted in table 2. We created "Digital" for our regression analysis as several of the transactions we recorded contained elements of both.
4. Columns E-H repeat the regressions presented in columns A-D, but exclude the "M&A: Total" variable. Since "M&A: Total" was insignificant in columns A-D, we dropped this to conserve degrees of freedom.
5. Heteroscedasticity-consistent standard-errors are in parentheses. An asterisk * denotes statistical significance at least at the 10% level.
6. Since our findings on R&D were the same as noted in table 8, we do not report them here.

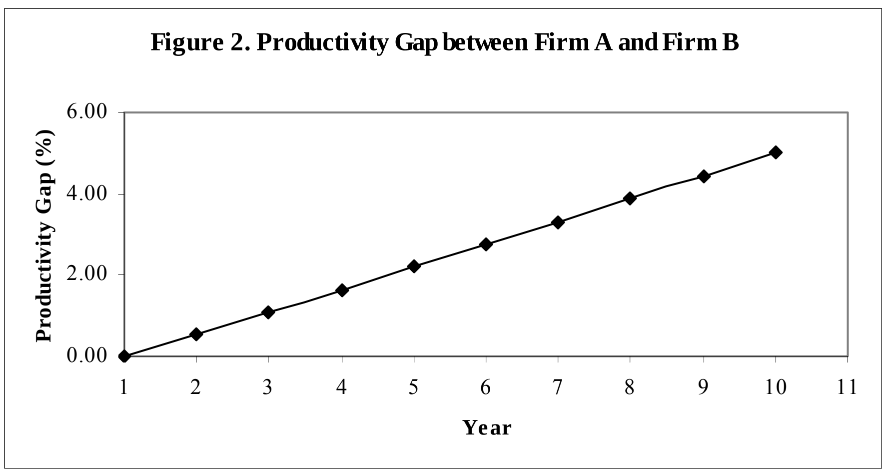
Table 10
Implied Quantitative Effects Based on the Estimated Coefficients in Table 9

	A	**B**	**C**	**D**
1. (K/L)	26.97* (8.01)	27.86* (8.33)	26.94* (7.17)	29.64* (8.79)
2. Patents	9.01* (3.08)	9.58* (2.90)	6.20* (2.78)	5.07 (1.45)
3. Mergers: Total	-5.45 (-1.03)	-4.99 (-0.90)	-2.72 (-0.65)	-1.36 (0.33)
4. TI: Total	**15.10*** (3.98)	–	–	–
5. TI: Mechanical	–	**13.45*** (2.82)	–	–
6. TI: Digital	–	–	**15.52*** (4.09)	–
7. TI: Chemical	–	–	–	**4.01** (0.65)
# Observations Adjusted-R^2	19 0.7961	19 0.7657	19 0.8072	19 0.6476

1. The implied quantitative effects are computed from the coefficient estimates presented in table 9 (columns A-D) and the summary statistics presented in table 3 and table 6. For each of the explanatory variables, the starting point are the means of the dependent variable and the explanatory variable. Then we consider a one-standard-deviation change in that explanatory variable (e.g., patents) and then compute the resulting change in the dependent variable (q/L).
2. The *t-statistics*, significance levels and adjusted-R^2 are the same as in table 9 – we repeat them here for convenience. An asterisk * denotes that the estimate is significant at least at the 10% level.
3. We do not report the intercept as it is not important for computing the quantitative effects of the explanatory variables.



Note: We assume that both firms start off in year 1 at our sample average productivity of $166,562 per worker. Subsequently, firm A experiences a 1.8% productivity improvement per year whereas firm B has 1.25% per year.



Note: In the starting year 1 there is no gap by construction. By year 10, firm A has a 5% higher productivity than firm B.