Is R&D Enough to Improve Firm Productivity?

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Abstract

Research and development (R&D) is critical to innovation that enhances productivity. Going beyond a simple relationship between R&D and firm productivity performance, this article investigates what co-investments and other business operating conditions facilitate R&D in improving productivity. Using a rich micro database for Canada, we show that the actual effect of R&D on productivity depends on a number of factors that play important roles in determining R&D efficiency in improving productivity. These factors include adopting certain management practices, making investments in ICT, and maintaining a skilled workforce. In addition, the article shows that firm size, foreign ownership and market power are important positive forces in improving R&D efficiency. The findings highlight the complexity of R&D in improving productivity.

Innovation generally refers to a firm's effort in the deliberate application of new ideas and information in the production of goods or services. Research and development (R&D) has long been believed to be the critical factor that drives firms to innovate (Romer, 1990; Aghion and Howitt, 1992). It enhances productivity directly by improving firms' technological capacity of applying new ideas and initiatives in production, and indirectly by nurturing internal expertise and developing in-house absorptive capacity. The built-up capacity enables firms to adopt more complex external production technologies and also to internalize external knowledge and information. Empirical literature shows that investments in R&D contribute to productivity performance (Griliches, 1979, 1986; Wakelin, 2001; Griffith et al., 2004; Hall *et al.*, 2010), although the evidence for Canada is weak (Mohnen 1992, Gu and

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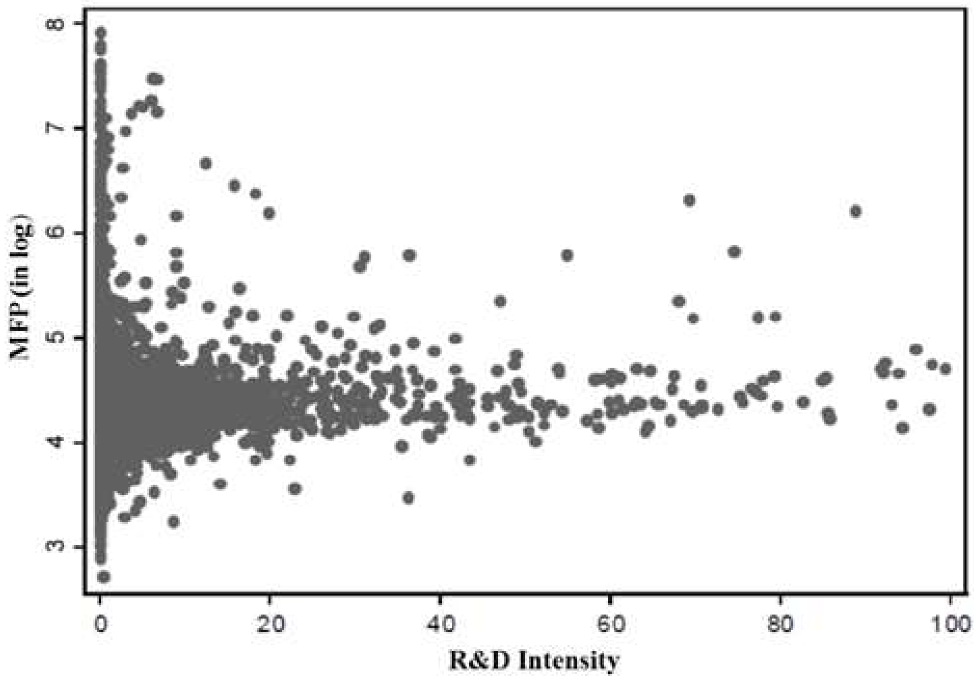
Chart 1: Multifactor Productivity and R&D intensity in Canadian Manufacturing



Source: Authors' compilation based on micro data from Statistics Canada.

Tang 2004).

Chart 1 presents multifactor productivity (MFP) against R&D intensity for Canadian manufacturing firms.[2] R&D intensity is defined as the ratio of R&D stock to total physical capital stock.[3] We observe that firms vary significantly in both MFP and R&D intensity. Importantly, the relationship between MFP and R&D is not obvious. Higher R&D effort does not necessarily mean higher MFP. The natural questions are: why does R&D improve productivity for some firms relatively more than for others and what factors determine R&D efficiency?

The relationship between productivity and R&D has commonly been evaluated in isolation from the business environment where a firm operates. This may not be appropriate as the relationship is likely affected by both internal and external factors associated with the firm. Internal factors are firm specific e.g. firm size and ownership, investments in technologies, management practices, and business strategies. The external factors consist of a variety of influences that are beyond the firm's control, which include institutions (e.g. legal framework and intellectual property regimes), financial conditions, economic conditions, and public infrastructure (e.g. Coe et al, 2009). In other words, the pro-

2 Productivity (or MFP) is commonly measured as a residual of gross output net the contribution from labour, capital and intermediate inputs

3 When R&D intensity is defined as the ratio of R&D stocks to gross output, similar results are obtained.

ductivity dividend yield from R&D investments depends on those internal and external factors. If a firm has no much control over the external factors, which are generally macro conditions and are the same to all firms operating in the environment, it can certainly maneuver internal factors to strive for a better productivity dividend yield. Governments may also design industry policies to encourage the firm to invest in business activities that support R&D. Internal factors may be at the core of the difference in R&D efficiency between firms.

Thus, without considering other factors that influence productivity, the evaluation of R&D effects by simply linking only actual productivity to R&D may be misleading. The objective of this article is to examine which internal factors facilitate R&D in improving productivity in the Canadian manufacturing sector.[4] we focus on MFP (thereafter productivity). The dataset used for the purpose has rich information on production, R&D investments, business operating environment, ownership, investments in technologies, management practices, and business strategies.

A stochastic frontier model is used for studying the impact of R&D on technological frontier and for identifying factors that facilitate R&D in improving productivity. It is a significant departure from the empirical literature that focuses on the actual effect and commonly ignores the fact that how R&D influences productivity depends on the business operating environment and co-investments. The stochastic frontier analysis is able to provide us with a more sophisticated understanding of the role of R&D in productivity improvements. In particular, it is able to distinguish between the potential (or maximum) productivity effect of R&D (or the frontier) and the inefficiency of R&D in improving productivity (or the distance from the frontier), with the latter being modelled as a function of certain internal factors.[5] The specification is desirable as it allows us to explain the differences in R&D efficiency among firms.

The specification and the identification of the factors that play important roles in affecting the effectiveness of R&D in improving productivity performance should be of considerable interest to both academics and policy makers. It helps elucidate which factors enhance R&D effectiveness in improving productivity performance. In addition, it can facilitate the diffusion of best practices and help firms improve R&D efficiency. Furthermore, it provides policy makers with the evidence to design more sophisticated and effective programs to promote and support innovation activities.

The article is organized as follows. In the first main section, we set up the stochastic frontier model that is tailored to our research objective. In section two, we describe the micro data and provide some de-

4 The manufacturing sector is focused due to data limitation.

5 Multiple regression models with interaction terms between R&D and other variables can be used to test the complementarity between R&D and other variables, but those models treat R&D the same as other variables and could not identify the maximum potential of R&D in improving productivity, and they also could not approach the linkage from an efficiency perspective.

scriptive statistics on how R&D firms perform compared to non-R&D firms. In section three, we discuss the results of our stochastic frontier analysis. In section four, the final section, we conclude.

Methodology: The Stochastic Frontier Model

Productivity measures how efficiently a firm can convert inputs into output. It is often considered as technological progress. In practice, however, it reflects a firm's technological development and efficiency improvement, and is determined broadly by the firm's efforts in innovation and in investing in efficiency-enhancing activities.

In this article, we assume that a firm's productivity is mainly driven by its innovation capacity associated with technological progress, which is supported by investments in efficiency-enhancing activities. The assumption is consistent with the fact that innovation capacity determines the firm's success in the deliberate application of new ideas and information in the production of goods or services, which is the core of business operation. Following the literature (e.g. Aghion and Howitt, 1992), we indicate the firm's innovation capacity by its past and current activities in R&D.

Other investments, such as investments in ICT, are mainly used to support and facilitate the core of business operation and are considered efficiency-enhancing investments. The rationale for treating those investments as efficiency-enhancing activities will be discussed in some detail towards the end of this section.

To empirically estimate the R&D potential (or interchangeably technological frontier) and the efficiency-enhancing activities in improving productivity, a stochastic frontier analysis is conducted.[6] Let A_i^* be the R&D potential for firm i and assume it is a function of variables that related to R&D intensity (R_i) and a set of controlling variables including foreign-control, year and industry dummies (Z_i):[7]

$$A_i^* = f(R_i, Z_i) \exp(v_i) \qquad (1)$$

The random error terms (v_i) are independently and identically distributed as $N(0, \sigma_v^2)$, reflecting the stochastic nature of the frontier as the frontier of the firm is not entirely under the control of the firm and is affected by random factors.

As discussed earlier, R&D is a process of applying new ideas and initiatives that requires a certain length of time to generate innovative products and production methods.[8] Thus, R&D is in stock. In addition, the square of the R&D intensity is included to capture a potential non-linear relationship between R&D and productivity. A number of empirical studies show

6 The stochastic frontier model was pioneered by Aigner *et al.*, (1977). Kumbhakar and Lovell (2000) provided an excellent introduction to stochastic frontier analysis.

7 Most R&D expenditures are on labour and materials. To avoid double accounting (with labour and intermediate inputs for production), R&D variables are entered the equation as R&D intensity, measured as the ratio of R&D stock to physical capital stock.

8 Lagged R&D variable is suggested in the literature, for example in Goto and Suzuki (1989) and Wang (2007), to reflect the delayed effect of R&D investment. Either one or two-year lagged R&D intensity are not sig-

that for certain industries, R&D investments are subject to diminishing returns (Zenger 1994, Faff *et al.*, 2013).

We control for foreign ownership as it is well known that R&D activities of foreign affiliates are subject to the headquarter effect, that is, foreign affiliates tend to do less R&D as R&D activities tend to be with their parent companies. In addition, it has been generally found that foreign-controlled firms in Canada are significantly more productive than Canadian-controlled firms. The foreign ownership productivity advantage is real and significant. It is believed that the advantage arises because foreign-controlled in Canada have the access to advanced technologies from their parents (Rao *et al.*, 2010; Tang and Rao, 2003).[9]

Year and industry dummies are introduced to capture business cycle effects and industry specific effects as technological opportunities and appropriability conditions appear quite different from one industry to another (e.g. Griliches and Mairesse, 1982; Pavitt, 1984).

Equation (1) is the technological frontier, representing the potential impact of R&D on productivity. However, not all firms are able to exploit R&D efficiently in improving productivity and the actual impact may be less than the potential. We assume that the efficiency of R&D in improving productivity depends on the firm's capacity in exploitation of the investments, which is influenced by a number of co-investments and other internal factors associated with firms' operations. Firm size, workforce skills, business operating environment, investments in technologies (including ICT), management practices, business outward orientation, and business strategies are included as the internal factors associated with firms' operations. Although the inclusion of the factors is largely driven by data availability, the coverage is comprehensive. In general, these factors may affect the efficiency of R&D in improving productivity because they influence firms' capacity, management, the economies scale and scope in exploitation of R&D. Thus, a firm's actual productivity (A_i) becomes

$$A_i = \underbrace{f\left(R_i, Z_i\right)\exp(v_i)}_{\text{Technological Frontier}}\ \underbrace{\theta(X_i)}_{\text{Efficiency}} = A_i^* \theta(X_i) \tag{2}$$

Where $A_i \leq A_i^*$ and $\theta(X_i) \in (0,1)$ represents R&D efficiency that is a function of a set of X variables influencing business efficient execution, including technology adoption, skills, better management, learning by doing, and capacity utilization. These X variables are commonly called the determinants of efficiency.

Equation (2) demonstrates the actual impact of R&D on productivity depends

nificant. This may be because R&D stock captures the effects from both current and past R&D investments. R&D investments (both in-house and purchased) are derived using data collected for the program supporting corporate's scientific research and experimental development (SRED). They are then used to build up R&D capital stock using Perpetual Inventory Method (PIM) at firm level with the depreciation rate being 15 per cent. Details are in Appendix B.

9 Note that similar results are obtained when we alternatively put the foreign ownership variable in the efficiency function.

on the efficiency-enhance X variables. The higher is the efficiency term, the closer to the potential impact is the actual impact of R&D on productivity.

Now we provide some rationale and theoretical discussion for the inclusion of the X variables. Firm size may impact on R&D efficiency. Larger-sized firms are able to benefit more from R&D than their small-sized counterparts as larger-sized firms can access lower-cost capital resources and in-house expertise/skills in commercializing successful R&D investments. They can also magnify the benefit of R&D from their larger scale and scope of production.

Skills have long been recognized as a crucial factor for R&D activities to be successful. They are essential elements for undertaking certain complex R&D investments, carrying out R&D activities efficiently, and internalizing the outcome by introducing new products and/or processes. There has been well documented evidence for the strong link between R&D and skilled labor (Morck and Yeung, 2000; Bernstein, 2002). Findings in Foley *et al.*, (1993) suggest that the lack of certain skills can act as a barrier to pursue certain business activities. Using firm-level data from the United Kingdom, Bosworth and Wilson (1993) show that there is a strong relationship between the deployment of highly qualified employees, their role in the strategic management of companies and firm dynamic economic performance.

A competitive business environment is generally considered to be positive for undertaking R&D activities. As competition threatens the viability of businesses, it reduces managerial slack and generates incentives to improve firm performance through product, process or organizational innovation (Nickell, 1996, Tang and Wang, 2005, and Tang, 2006). However, for a given R&D activity, the return on R&D investment may depend on the firm's ability or market power in commercializing R&D products (Demsetz, 1973; Peltzman, 1977).

Investments in ICT and other technologies are also efficiency-enhancing since technologies streamline R&D operations, minimize redundancies, and increase accuracy and reduce errors. In a broad context, ICT are believed to be enablers of product, process and organizational innovation (Teece 1986; Bresnahan and Trajtenberg, 1995). They also play a substantive role in the generation, storage and transmission of information and in the reduction of market failures (Biagi, 2013). The increased use of ICT has been credited with the strong resurgence of productivity growth in the United States and many other OECD countries (Jorgenson, 2001; Stiroh, 2002; Timmer and van Ark, 2005; and van Reenen *et al.*, 2010).

Management may also matter for the productivity impact of R&D because it is empowered for the strategic planning, priority setting, development and coordination of R&D programs. It also oversees day-to-day R&D operations and facilitates the absorption, implementation and commercialization of new know-how and technology from R&D. There is empirical evidence showing a robust and causal impact of managerial quality/practices on firm performance (Nelson, 1991; Bloom and Van Reenen, 2010; Bloom *et al.*, 2013b). Bloom *et al.*, (2012) attributed at least one-half of the difference in productivity growth between the United States and some European countries in 1995-2004 to superior management practices in the United States.

Like management, business strategies (e.g. product positioning against cost leadership, outward orientation) may matter for R&D efficiency. It has been suggested that to be successful in the current global economy with increased competition and ever changing markets, firms need to focus more on product positioning by exploring new ideas and designing new products to develop new markets than on cost-cutting to maintain cost leadership in old markets (Su and Tang, 2016). This is because product innovation allows firms to develop and maintain a lasting, sustainable competitive advantage (Brown and Eisenhardt, 1995; Porter, 1985). In addition, it has been suggested that outward-oriented business strategy (exporting, offshoring, and undertaking outward foreign direct investments) is also important for firm performance (Trefler, 2004; Baldwin and Gu, 2004; Tang and Van Assche, 2017). In the context of this article, outward-orientation strategies may increase R&D efficiency as they effectively increase the market available in which firms can spread the fixed costs associated with R&D investments. They also allow for better access to production resources, advanced technologies and products, and better management practices.

With this formulation, the actual productivity is specified as two components: the "technological frontier" and the "efficiency". Regardless of the terminologies, the first term is driven by the R variables while the second one is driving by the X variables. They complement each other to improve productivity. The separation is to estimate the maximum potential of R&D in affecting productivity. Thus, the frontier here should be interpreted as the technological potential and is the maximum influence of R&D on actual productivity.

For our empirical analysis, we assume that $\ln \{f(R_i, Z_i)\}$ is linear in its R&D and controlling variables. Also, following the tradition under the stochastic production frontier framework, we define $u_i = -\ln \theta_i$. This yields the following stochastic frontier regression model:

$$\ln(A_i) = \beta_0 + \beta_1 R_i + \beta_2 R_i^2 + \sum_{j=3}^{s} \beta_j Z_{i,j} + v_i - u_i \ , \quad (3)$$

where $u_i \geq 0$ is an additional error term, which a measure of inefficiency or shortfall of R&D in improving productivity to the maximum.[10]

Following Stevenson (1980), we specify u_i as a one-sided error term, independently and normally distributed with nonzero mean and truncation point at 0, $N^+(\mu_i,\ \sigma_u^2)$.[11] We hypothesize that the mean of the distribution of inefficiency is heterogeneous across firms, depending on a set of the factors that may influence R&D efficiency in improving productivity. We formulate the mean of the truncated-normal distribution for firm i as a linear

10 Note that $u_i = -\ln(\theta_i) \approx 1 - \theta_i$.

11 The superscript "+" refers to truncation on the left at zero.

function of those covariates:

$$\mu_i = \gamma_0 + \sum_{h=1}^{m} \gamma_h X_{i,h} \quad (4)$$

where X_i is a vector of the covariates that may affect R&D in improving productivity.[12]

Data

To estimate the stochastic frontier regression model, we construct a firm-level dataset by linking four micro-data files compiled by Statistics Canada.[13] We list the variables extracted and derived from each micro database in the Appendix at the end of this article. Here we provide a brief description of each of those four micro-data files.

Micro-data Files

The first micro data file is General Index of Financial Information (GIFI). The administrative micro data file collects financial statement and balance sheet information from each firm when it files a T2 Corporation Income Tax Return. We extract information from this dataset and derive a firm's gross output, physical capital stock, and intermediate inputs. In addition, we obtain data on R&D stock and ICT stock, which are also derived from information from the tax files. The definition of some variables will be discussed in the next section.

The GIFI data is then supplemented by payroll and employment information for each employer business in Canada from The National Accounts Longitudinal Microdata File (NALMF). The data in NALMF come from various sources, mainly administrative data from statement of remuneration paid (T4), statement of account for current source deductions (PD7), corporate income tax return (T2) and goods and services tax (GST) files. Firm characteristics such as industry and ownership for example come from Statistics Canada's Business Register. For this study, we select Individual Labour Unit (ILU) as a firm's employment. This measure is closer to a head count — every individual who received at least one T4 slip in a given year. If individuals worked for different firms during the year, their 1.0 ILU is split proportionately across firms according to the share of their total annual payroll earned in each.[14]

12 With this model, we do not deal with the endogeneity issue associated with productivity and its explanatory variables. Given that R&D and ICT variables are measured as stock (mainly depending on past investments) and other variables are mostly perception-based, we do not expect this is a significant problem.

13 These micro files can be accessed for empirical analysis at Statistics Canada. Researchers wishing to access these and other micro files must submit a research proposal to the Canadian Centre for Data Development and Economic Research (CDER) at Statistics Canada.

14 Another employment measure, the Average Labour Unit (ALU), is also available if it is requested. ALU is derived by dividing the business's annual payroll (from T4) by the corresponding industry/province/size class average annual earnings per employee (from the Survey of Employment Payroll and Hours). Because the imputation is based on average payroll, it will overestimate employment of productive firms and underestimate employment of less productive firms since high productive firms in general pay high wages. Note, however, that ILU also has its own shortcomings. It overestimates employment of firms with part-time workers. The problem may be minimized by the introduction of industry dummies in the analysis.

In addition, the GIFI data is supplemented with data on foreign ownership from the Business Register (BR) through NALMF. BR is the central repository of information on businesses in Canada. Used as the principal frame for the economic statistics program at Statistics Canada, it maintains a complete, up-to-date and unduplicated list on all active businesses in Canada that have a corporate income tax (T2) account, are an employer or have a goods and services tax account.

These three databases are administrative microdata, covering all industries and for 2000-2014. The linkage of these three databases provides necessary data for our analysis, including output, inputs (labour, capital and intermediate inputs), R&D, investments in ICT (computers, communication equipment and software), and certain information on firm characteristics such as foreign ownership.[15]

Missing from these administrative micro databases are firms' business environment, business strategy, and management practices, which play very important roles in influencing the effectiveness of R&D in improving productivity. We are able to obtain these data from the Survey of Innovation and Business Strategy (SIBS) (2009 and 2012). SIBS is a sample-based survey that provides qualitative information about a firm's strategic decisions and operational tactics. The targeted population consists of firms in Canada with more than 20 employees and revenues of at least $250,000 in 14 sectors at the two-digit industry level from 11 to 56 based on the North American Industrial Classification System. SIBS surveyed 4,228 firms in 2009 and 4,467 firms in 2012, with 1,279 firms being in both time periods.

To ensure comparison over time, it is necessary to deflate the nominal variables associated with the production function. Deflators at the firm level are not available so detailed industry deflators based on the KLEMS database are used.[16] In particular, total sales, physical capital assets, payroll per employee, and the derived intermediate inputs at the firm level are deflated by gross output, capital stock, value added and intermediate input deflators at a detailed industry level.

For this research, our analysis focuses on Canadian manufacturing firms. There are three main reasons. First, the linked micro database is limited to only sample firms in SIBS. Manufacturing firms account for about 70 per cent of the sample firms. Second, relative to service industries, output and inputs for manufacturing are less likely subject to measurement errors. Finally, the link between R&D and productivity is not that straightforward for some service industries as the major business activities for some service firms are pure R&D in nature, with little application of R&D or production activities.

After linking to the sample-based surveys to the three administrative micro databases and limiting to only manufacturing firms, we end up with 2,537 and 2,356 observations in 2009 and 2012, re-

15 Gross output and inputs (labour, capital and intermediate inputs) are used to derive productivity estimates.

16 For a description of the KLEMS database for Canada, see Baldwin *et al.* (2007).

spectively. The final observations and the distribution by industry are reported in Table 1. On average, more than half of them were R&D performers, although there was a great variation across manufacturing industries.

Some Descriptive Results

Industries vary significantly in R&D intensity (Table 2). On average, the most R&D intensive industry was computer and electronics, followed at distance by electrical products and appliances and machinery. In contrast, the least R&D intensive industries were wood, beverage and tobacco, and non-metallic mineral.

In terms of the standard deviation, there was a significant variation in R&D intensity across firms within an industry. On average, the standard deviation is about 7 times the mean.

In general, R&D performers were larger than non-R&D firms in both output and employment (Table 3). In addition, they were more productive, paid higher wage rates, and were more physical capital intensive.[17]

The comparison in economic performance between R&D performers and non-R&D firms is a good starting point, but to understand the difference, we need a more rigorous analysis on the factors underlying these disparities. We focus on productivity.

Stochastic Frontier Analysis

In this section, we empirically estimate the effect of R&D on productivity and see how the actual impact of R&D is influenced by firm specifics (e.g. firm size and ownership), workforce skills, business operating environment, investments in technologies (including ICT), management practices, business outward orientation, and business strategies.

Variable Definition and Measurement

Before discussing the empirical results, we first briefly describe the definition of some key variables in the empirical analysis. The definitions and measurements of all variables are found in Table A2 in the Appendix.

For the regression model, equation (3), the actual multifactor productivity for firm i, $\ln(A_i)$, is estimated as the Solow residual, that is, real gross output minus the contributions from inputs (labour, real physical capital, and real intermediate inputs), with parameters being obtained by estimating each industry production function, controlling for year-specific effects.[18]

The physical capital stock here consists of assets associated with machinery, equipment, and building structures, excluding R&D.

The technological frontier is a function of R&D, controlling for foreign ownership,

17 The differences between R&D firms and non-R&D firms for all variables except capital intensity are statistically significant.

18 The actual multifactor productivity for firm i in an industry is calculated as $\ln(A_i) = \ln(Y_i) - \hat{\alpha}_L \ln(L_i) - \hat{\alpha}_K \ln(K_i) - \hat{\alpha}_M \ln(M_i)$, with the estimated parameters being industry-specific.

Table 1: Number of R&D and non-R&D performers by Manufacturing Industry, 2009 and 2012

Industries	2009			2012		
	No-RD	RD	Total	No-RD	RD	Total
Food	128	109	237	141	65	206
Beverage and tobacco	X	X	X	X	X	X
Textile mills and textile	37	58	95	44	38	82
Clothing and leather	58	39	97	50	32	82
Wood	83	55	138	89	44	133
Paper	48	50	98	37	41	78
Printing and support	51	44	95	63	35	98
Petroleum and coal	X	X	X	X	X	X
Chemical	52	113	165	54	93	147
Plastics and rubber	71	103	174	84	80	164
Non-metallic mineral	58	40	98	65	28	93
Primary metal	35	66	101	49	42	91
Fabricated metal	132	107	239	123	98	221
Machinery	75	145	220	70	126	196
Computer and electronic	27	116	143	34	109	143
Electrical, appliance and components	38	75	113	45	69	114
Transportation equipment	109	165	274	108	137	245
Furniture and related product	67	42	109	84	27	111
Miscellaneous manufacturing	42	53	95	68	43	111
Total manufacturing	1,136	1,401	2,537	1,237	1,119	2,356

Note: X denotes numbers being suppressed for confidentiality.
Source: Authors' tabulation based on micro data from Statistics Canada.

Table 2: R&D Intensity and Variation by Manufacturing Industry, 2009 and 2012

Industries	2009		2012	
	Mean	St. D.	Mean	St. D.
Food	0.33	3.89	0.14	0.53
Beverage and tobacco	X	X	X	X
Textile mills and textile	0.49	2.05	1.36	8.09
Clothing and leather	0.71	3.80	0.37	0.80
Wood	0.03	0.09	0.06	0.22
Paper	0.14	0.42	0.23	1.13
Printing and support	0.19	0.80	0.18	1.14
Petroleum and coal	X	X	X	X
Chemical	1.24	5.91	0.61	1.86
Plastics and rubber	0.30	0.75	0.16	0.43
Non-metallic mineral	0.07	0.17	0.09	0.28
Primary metal	0.35	2.04	0.32	1.93
Fabricated metal	0.64	6.10	1.47	16.88
Machinery	0.76	1.90	1.62	6.47
Computer and electronic	9.12	29.32	5.86	11.52
Electrical, appliance and components	1.47	4.27	1.08	3.17
Transportation equipment	1.00	5.88	0.91	4.95
Furniture and related product	0.11	0.43	0.13	0.65
Miscellaneous manufacturing	0.72	2.00	0.62	2.06
Total manufacturing	1.06	8.08	0.97	6.78

Notes: X denotes cell being depressed for confidentiality. R&D intensity is defined as the ratio of R&D stock to physical capital stock
Source: Authors' tabulation based on micro data from Statistics Canada.

Table 3: R&D Performers and Economic Performance, Total Manufacturing

	2009		2012	
	R&D Firms	Non-R&D Firms	R&D Firms	Non-R&D Firms
Average firm real gross output, million$	108.9	29.6	138.2	28.1
Average firm employment	286.5	132.8	269.2	105.6
Average firm real wage rate, 000$	42.2	38.3	44.9	40.1
Average firm capital intensity,000$	139.3	124.0	116.2	113.5
Average firm labour productivity, 000$	216.0	204.3	239.6	206.8
Average fir MFP level (non-R&D firms = 100)	101.3	100.0	101.8	100.0

Notes: Real wage rate, capital intensity, and labour productivity are defined as real labour compensation per employee, physical capital stock per employee, and real gross output per employee, respectively. MFP is calculated as residual of real gross output minus contributions from labour, physical capital and intermediated inputs with parameters being estimated through regressions.
Source: Authors' tabulation based on micro data from Statistics Canada.

business cycles and industry-specifics. The set of R&D variables consists of R&D intensity and its square. To capture a firm's R&D investment in the current and the past years, R&D intensity in this paper is measured as the ratio of R&D stock to physical capital stock.[19] R&D stock for each firm is estimated from real R&D investment using the perpetual inventory method, assuming a capital depreciation rate of 15 per cent.[20] Foreign ownership is a dummy variable with one being foreign-controlled and zero otherwise.

In the X variables for efficiency, firm size is a continuous variable measured by employment. Workforce skills are approximated by the percentage of employees with university education. Business competitive environment is indicated by the firm's market share and the firm's perception of its market power (in terms of market share, number of competing products or number of competitors) in its main market. As shown by Tang (2006), the advantage of the perception-based competition indicators comparing to industrial statistics is that (a) they are able to capture firm-specific competition as firms may face different competition even within a narrowly defined industry and (b) they reflect not only competition from domestic markets but also competition from foreign markets. As shown in Table A3 of the Appendix, the index is valued between 0 and 1. The higher is the index value, the larger market power the firm has.

For investments in technologies, we include two indicators. One is the investment in ICT. To indicate the effort in investment in ICT, we use ICT intensity and define it as the ratio of ICT stock to physical capital stock. The other is an index for adopting any non-computerized advanced technologies associated with automated material handling, information integration and control, biotechnologies and bio-products, nanotechnologies, green technologies, and other type of advanced technology. Those technologies may take the form of equipment, materials, processes, blue prints and

19 We use physical capital stock to scale down R&D stock instead of output as we also use physical capital stock to scale down ICT stocks. Results will be similar when output is used as a scale down variable.

20 See Appendix for a discussion on how R&D investment and R&D capital stock are derived.

knowledge. There are in total six non-computerized advanced technology indicators. Each indicator is a binary variable, with one for being adopted and zero otherwise. The index is a simple average of the six binary variables.

For management practices, following Brouillette and Ershov (2014), we construct an index based on a framework developed by Bloom and Van Reenen (2007). Basically, the index is a simple average of 19 indicators. The indicators, which are listed in Table A3 in the Appendix, are normalized between 0 and 1, reflecting firm production performance and human resource management practices from various aspects. The index is valued between 0 and 1. Based on Bloom *et al.*, (2013a), the higher the index value, the more structured are the management practices.

Business outward orientation refers to a firm's outward orientated strategy in terms of taking advantage of international markets for cheap inputs and for selling outputs, which may increase the returns to R&D investments. The index for business outward orientation is built based on two indicators. The first indicator is business activities outside of Canada, including business operations in foreign countries. If a firm has any business activities outside of Canada, then the indicator is one and zero otherwise. The second indicator is exporting. The indicator equals one if a firm exports or attempts to export and zero otherwise. The index for business outward orientation is a simple average of the two indicators.

The final variable being considered is forward-looking business strategy. It is defined as a strategy related to product positioning, which includes product leadership, market segmentation, product diversification and improving quality. If a firm has its long term strategies mostly focusing on product positioning, then it is equal to one; zero otherwise.

Discussion of Empirical Results

The stochastic frontier regression model is estimated using the linked micro database.

Estimation results

The estimation results for R&D performers are reported in Table 4.[21] Several interesting results emerge. For the R&D potential or technological frontier, it is found that the R&D intensity variable was positive and highly significant and its square was negative and highly significant. Thus, the estimation shows that R&D investments are highly significant in raising productivity, but they are subject to diminishing return as R&D investments increase. [22] As expected, the coefficient on the foreign ownership dummy is positive and significant, suggesting that, ceteris paribus, foreign controlled firms' technological frontier are about 12 per cent more shifted outward than domestic controlled firms' in our sample.

For the inefficiency function, all vari-

21 The stochastic frontier model is estimated in two stages. For a discussion, see Kumbhakar *et al.*, (2015).

22 Main results are similar when R&D intensity is defined as R&D stock per worker.

Table 4: Stochastic Frontier Estimation, R&D Performers in Canadian Manufacturing

Dependent variable: log of MFP	Parameter	p-value
Technological frontier		
Constant	4.4696	0.64
R&D intensity	0.6828***	0.00
Square of R&D intensity	-0.1927***	0.00
Foreign owner ship dummy	0.1177***	0.00
Year dummies	Yes	
Industry dummies	Yes	
Inefficiency		
Management practice index	-0.0723***	0.00
ICT capital intensity ratio	-0.2135***	0.00
University Education (in log)	-0.0318***	0.00
Employment (in log)	-0.0095***	0.01
Firm market power	-0.0815***	0.00
Non-computerized technology adoption index	-0.0146	0.44
Outward orientated business strategy index	0.0038	0.71
Product positioning business strategy dummy	-0.0204*	0.10
Constant	0.5972	0.95
Number of observations	2520	

Note: R&D intensity for the regressions is scaled down by 100 to ensure the coefficients associated with R&D variables are not zero in 4-digit decimal numbers. "**" and "***" stand for significance at 5 per cent and 1 per cent level, respectively.
Source: Authors' tabulation based on micro data from Statistics Canada.

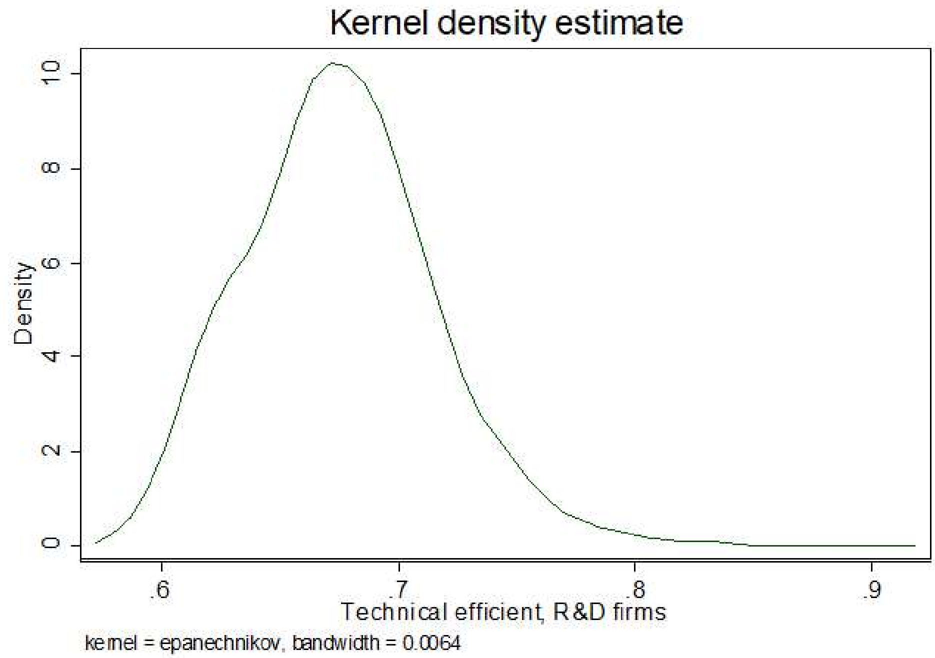
ables except non-computerized technology adoption and outward orientated business strategy are found to be statistically highly significant. Inefficiency measures the distance of actual multifactor productivity from the technological frontier. Negative for inefficiency means positive for efficiency. Thus, firms that pursued sound management practices, invested in ICT, had skilled workforce, were larger, and adopted the product positioning business strategy tend to be closer to the frontier. In addition, the estimated coefficient associated with a firm's market power is also negative and significant, which suggests that market power or share is important for the return to R&D investments.[23]

The statistical insignificance of non-computerized technology adoption or outward orientation is surprising as they increase the capacity or market to better exploit R&D investments. The lack of significance is not because those factors are correlated with those significant factors in the inefficiency function. For instance, dropping ICT intensity from the regression will not make non-computerized technology adoption significant. Similarly, the exclusion of employment and foreign-control dummy from the regression does not change the sign and the significance of the coefficient associated with outward orientated business strategy.

In sum, the estimation shows that for R&D to generate its potential productivity dividend, it is important to have co-

23 The result is consistent with the positive relationship between efficiency and market share or markups (Demsetz, 1973 and Peltzman 1977).

Chart 2: R&D Efficiency Distribution for R&D Firms



Source: Authors' tabulation based on micro data from Statistics Canada.

investments in ICT, pursue certain management practices, maintain skilled workforce, achieve a certain scale, retain a certain level of market share, and adopt the product positioning business strategy. The lack of these efforts and conditions undermine the R&D efficiency in improving productivity.

Chart 2 is the R&D efficiency distribution for R&D performing firms.[24] Most of the firms had inefficiency between 20 and 40 per centt. Thus, besides encouraging firms to undertake R&D activities, effort to enhance business conditions to improve R&D efficiency is also equally important to improve firms' productivity and competitiveness.

Elasticity of Productivity with Respect to R&D and Efficiency-enhancing Co-variates

How is productivity sensitive to R&D and efficiency-enhancing factors? In this sub-section, we estimate the elasticity of multifactor productivity with respect to each of those factors. According to equation (4), actual MFP is a function of both deterministic components and random components. This means that the actual MFP is also random. To be meaningful, we avoid the randomness and calculate

24 R&D efficiency for firm i at time t is estimated as $TE = \exp(-\hat{u}_{i,t})$.

the elasticity of productivity with respect to a factor based on the mean of actual MFP, that is,

$$E\left[\ln\left(A_i\right)\right] = E\left[\ln\left(A_i^*\right)\right] + E\left[\ln\theta\left(X_i\right)\right] \ , \quad (5)$$

Based on equation (3), the marginal effect of the R&D on the frontier for firm i is $(\hat{\beta}_1 + 2\hat{\beta}_2\bar{R})\bar{R}$, with $\hat{\beta}_1$ and $\hat{\beta}_2$ being the estimated coefficients associated with the R&D variable and its square, respectively. $\bar{R}$ is the average of the current R&D variable across firms in the group. The marginal effect of foreign ownership dummy is $\hat{\beta}_3$, the estimated coefficient associated with the foreign ownership dummy.

According to Wang (2002), the marginal effect of $X_{i,h}$ on the mean of efficiency is as follows:

$$\begin{aligned}\frac{\partial E\left[\ln\left(A_i\right)\right]}{\partial X_{i,h}} &= \frac{\partial E\left[\ln\theta\left(X_i\right)\right]}{\partial X_{i,h}} \\ &= -\frac{\partial E\left(u_i\right)}{\partial X_{i,h}} \\ &= -\gamma_h\left\{1 - \Lambda_i\left[\frac{\phi\left(\Lambda_i\right)}{\Phi\left(\Lambda_i\right)}\right] - \left[\frac{\phi\left(\Lambda_i\right)}{\Phi\left(\Lambda_i\right)}\right]^2\right\} \ , \quad (6)\end{aligned}$$

where $\Lambda_i = \mu_i/\sigma_u$, and ϕ_i and Φ_i are the probability density and cumulative distribution functions of a standard normal distribution, respectively.

With the marginal effects, we can now estimate the elasticity of MFP (either the frontier or efficiency) with respect to each of those variables in the analysis. We separate factors that are continuous from those that are binary. Also for simplicity, we treat all variables other than those binary variables as being continuous. Furthermore, we only consider factors that are statistically significant. Finally, all elasticities are evaluated at the mean of corresponding variables across the group of sample firms.

For variables associated with the efficiency function, the impact of their changes on R&D efficiency and thus MFP depends on how they enter into the equation. For continuous variables in log, which are university education and employment, the elasticity of MFP with respect to a variable is the estimated marginal effect. For any other continuous variable, the corresponding elasticity is the product of the marginal effect of the variable and the average of the variable across firms in the group. For a binary variable, when the binary variable switches from 0 to 1, the productivity elasticity equals the estimated marginal effect times 100.

The average elasticities of MFP with respect to R&D variables by industry based on R&D performers and all firms are reported in Table 5. We calculate elasticities based on the estimated coefficients from R&D performers. According to elasticities on the basis of R&D performers, doubling the R&D intensity level from 1.8 (which was the actual average of R&D intensities of all R&D performers) to 3.6 will lead to a 1.2 per cent increase in MFP for the manufacturing as whole. The responses vary significantly across industries as industries vary in R&D intensity. The MFP increase from a doubling od the R&D intensity will be 5.9 per cent for computer and electronics, followed by 1.5 per cent for fabricated metal, 1.3 per cent for electrical, appliance and components. The smallest response is from wood, food and beverage and tobacco, less than 0.1 per cent.

Table 5: Average Elasticity of R&D in Improving Multifactor Productivity by Industry in Manufacturing

Industries	R&D firms
Wood	0.0005
Food	0.0012
Beverage and tobacco	0.0012
Non-metallic mineral	0.0013
Petroleum and coal	0.0014
Paper	0.0015
Furniture and related product	0.0023
Plastics and rubber	0.0028
Printing and support	0.0030
Primary metal	0.0039
Chemical	0.0084
Clothing and leather	0.0089
Textile mills and textile	0.0093
Transportation equipment	0.0094
Miscellaneous manufacturing	0.0094
Machinery	0.0110
Electrical, appliance and components	0.0128
Fabricated metal	0.0152
Computer and electronic	0.0590
Total manufacturing	0.0122

Source: Authors' tabulation based on micro data from Statistics Canada.

Table 6: Average Elasticity of Multifactor Productivity With Respect to Variables in Improving R&D Efficiency, Total Manufacturing

Factors	The Mean Value of Factors	Elasticities
Employment	278.81	0.0095
ICT capital intensity	0.06	0.0131
University education	16.35	0.0318
Firm's market power	0.40	0.0325
Management practice index	0.56	0.0405

Source: Authors' tabulation based on micro data from Statistics Canada.

In Table 6, we also report average elasticity of MFP with respect to other factors in equation (6) for total manufacturing on the basis of estimation for R&D performers. The impacts of those factors affect R&D efficiency and thus MFP depend on the changes in those factors?

To illustrate, here we provide an example for each factor. If management practice is more structured with a 25 per cent increase in the average index from 0.56 to 0.70, then MFP or R&D efficiency will increase 1.01 per cent. Similarly, if ICT capital intensity, the share of university education in workforce, employment, and firm's market power are doubled from 0.06 to 0.12, 16.35 per cent to 32.70 per cent, 279 employees to 558 employees, and 0.40 to 0.80, then R&D efficiency or productivity will increase by 1.31 per cent, 3.18 per cent, 0.95 per cent, and 3.25 per cent, respectively.

Finally, firms with product positioning business strategy dummy are 2.04 per cent more efficient than other firms (see Table 4).

Conclusion

Why do some manufacturers obtain a larger productivity dividend from their R&D investments than others? By estimating a stochastic frontier model based on a rich micro database for Canadian manufacturing firms, this article shows that R&D does improve productivity; however the actual impact of R&D depends largely on R&D efficiency in improving productivity. Empirical evidence indicates that there is a set of internal factors that work together in influencing R&D efficiency. These factors include management practices, investment in ICT, skilled workforce, firm size, firm's market power, and product positioning business strategy.

The findings highlight the complexity of R&D in improving productivity. They suggest that, to strive for a high productivity dividend yield from R&D investments, firms need to invest in other business activities that support R&D and its commercialization. They may also suggest that other industrial programs may be required to ensure R&D programs (R&D grants and R&D tax measures) to be more effective.

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Data Appendix

For productivity analysis outputs and inputs need to be properly measured to reflect production over a certain period. General Index of Financial Information (GIFI) provides firms' income statements and balance sheets. The income statement of a firm records incomes received and expenses incurred in both of its production and non-production activities. For using the information for productivity analysis, only production-related items should be included in the calculation of firms' outputs and inputs.

Table A1 presents the algorithm used to derive firm-level gross output, capital and labour income and intermediate input.

R&D expenditures are derived using data collected for the program supporting corporate's scientific research and experimental development (SRED). SRED program provides tax incentive in support of R&D activities of Canadian firms.

Firms' current and capital expenditures are reported in the tax form T661 that reports both allowable and qualified R&D expenses.[25] R&D investment can be measured as R&D investment = in-house R&D + purchased R&D (contract-out R&D or third-party R&D) - contract-in R&D (R&D performed for others).

Nominal R&D investment is then deflated using the implicit price index for R&D investment of all industries that is derived from CANSIM table 031-0007. The deflated or real R&D investment is then used to build up R&D capital stock using Perpetual Inventory Method (PIM) at firm level. Specifically, the current R&D capital stock (RDK_t) is equal to the previous R&D capital stock (RDK_{t-1}) net of depreciation at the rate of δplus current R&D investment (RDI_t), i.e.

$$RDK_t = (1-\delta)RDK_{t-1} + RDI_t$$

for $t = 2001$ to 2014.

The PIM calculation of capital stock requires a time series for investment data, information on the initial capital stock at the time and information on the depreciation rate. A constant geometric depreciation rate ($\delta = 15\%$) is used. Following Kohli (1982), the initial capital stock is calculated as

$$RDK_0 = \begin{cases} \frac{\overline{RDI}}{g_I+\delta} & \text{for firms born before 1985} \\ \frac{(\text{firm age})\times\bar{I}^{RD}}{g_I+\delta} & \text{for firms born after 1985 and before 2000} \\ 0 & \text{for firms born after 2000} \end{cases}$$

where $\overline{RDI}$ is the average R&D investment over the sample period, g_I the average annual growth rate of R&D investment over the sample period, and $\bar{I}^{RD}$ is the average R&D expenditure in 1985-2000.

Note that for young firms (less than 15-year old), their initial R&D capital stock at the year of 2000 is adjusted by the ratio of their age to 15.

25 See Lester *et. al.*, (2017) for a detailed discussion on how R&D expenditure can be measured.

Table A1: Algorithm for Deriving Nominal Output and Input Costs

	Gross Output (raw)
	Total sales of goods and services
+	Interest income for financial institutions
+	Commissions
+	Rental income
+	Fishing revenue
+	Management and Admin fees
+	Telecommunications revenue
+	Consulting fees
+	Sales of by-products
+	Deposit, Credit and Card services
	Total Cost
	Cost of sales
+	Operating expenses
	Profit
	Profit = gross output (raw) − total cost
	Labour Income
	Direct wages in cost of sales
+	Benefits on direct wages in cost of sales
+	Trades and sub-contracts in cost of sales
+	Employee benefits
+	Life insurance on executives
+	Salaries and wages
+	Sub contracts
	Capital Income
	Profit (if positive)
+	Gross overriding royalty
+	Freehold royalty
+	Other lease rentals
+	Exploration and development
+	Crown charges
+	Royalty costs
+	Freight-in and duty
+	Direct cost amortization of tangible assets
+	Direct cost amortization of resource assets
+	Donations
+	Amortization of intangible assets
+	Goodwill impairment loss
+	Bad debt expense
+	Loan losses
+	Amortization of resource assets
+	Amortization of tangible assets
+	Interest expense
+	Business taxes, licences and memberships
+	Government fee
+	Nova Scotia tax on large corporations
+	Property taxes
+	Royalty expenses
+	Research and development
+	Withholding taxes
+	Interfund transfer
	Intermediate input
	Intermediate input = gross output − labour income − capital income

The algorithm is for all industries including non-manufacturing. For companies with negative profit, gross output is measured by the shadow values of their business activities to ensure that capital cost/income is non-negative.

Table A2: Variable Definition, Measurement and Data Sources

Symbol	Name	Data sources	Measurement description
Y	Nominal gross output	GIFI	Total sales of goods and services plus other incomes such as commissions, management and admin fees, and consulting fees
L	Labour	NALMF	Individual Labour Unit (ILU)
K	Capital Stock	GIFI	Total tangible capital assets
k	Capital intensity	derived	The ratio of capital (K) to employment (L)
C^L	Labour compensation	NALMF	Wage and Salaries
C^K	Capital compensation	GIFI	All costs associated with the use of capital services
M	Nominal intermediate inputs	derived	Gross output minus labour costs (C^L) and capital cost (C^K).
LP	Labour productivity	Derived	Real gross output divided by employment
MFP	Multifactor productivity	Derived	Calculated as $\ln(A_i) = \ln(Y_i) - \hat{\alpha}_j^L \ln(L_i) - \hat{\alpha}_j^K \ln(K_i) - \hat{\alpha}_j^M \ln(M_i)$ with the parameters for industry j being estimated through the estimation of the production function
W	Wage rate	derived	Labour compensation (C^L) divided by employment (L)
R	R&D stock	GIFI	Derived using PIM model with 15% depreciation rate. For a more detail, see Appendix B.
R^{INT}	R&D intensity	derived	Ratio of R&D stock (R) to capital stock (K)
K^{ICT}	ICT capital stock	GIFI	Including computer equipment/software and radio and communication equipment.
k^{ICT}	ICT intensity	derived	The ratio of ICT capital stock (K^{ICT}) to capital stock (K)
D^F	Foreign ownership dummy	BR	1 for foreign controlled and 0 for Canadian-controlled
D^I	Outward-orientated business dummy	SIBS	1 for taking any business activities outside of Canada or for exporting or attempting to exporting; 0 otherwise
T	Adoption of technology	SIBS	An index that equals the simple average of six non-computerized advanced technology adoption indicators related to automated material handling, information integration and control, biotechnologies or bio-products, nanotechnologies, and green technologies
D^{BS}	Product positioning strategy	SIBS	1 for focusing on product positioning (e.g. product leadership, market segmentation, product diversification, improving quality) being the most important long term strategies; 0 for focusing on low-price and cost leadership (e.g., mass market) being the most important long term strategies
M	Management practices	SIBS	An index that equals the simple average of 19 normalized management practices indicators associated with production performance and human resources; more details are provided in Table A3 in Appendix A.
U	Education of workforce	SIBS	Percentage of employees having a university degree
C	Competition	SIBS	An index that equals the simple average of three normalized indicators that are associated with the market power that are against a firm in its main market. The first indicator is one minus the market share of a firm in its main market. The second and the third are normalized indicators on the number of competitors and competing products in the firm's main market such that 1/7 for 1, 2/7 for 2, 3/7 for 3, 4/7 for 4-5, 5/7 for 6-10, 6/7 for 11-20, and 1 for more than 20.
Ps	Deflators	KLEMS National Accounts	For gross output, capital, value added, intermediate inputs, and R&D spending.

Table A3: Management Indicators from SIBS

Indicators	Normalized value
Production Performance Management Practices	
Systematic procedure to resolve production problems	0 for no, and 1 for yes
Number of key production performance indicators	0 for none, and 1 for at least one
The frequency that the key production performance indicators are shown to managers	0 for never or don't know, and 1 for any frequency
The frequency that the key production performance indicators are shown to workers	0 for never or don't know, and 1 for any frequency
The frequency that the key production performance indicators are shown to executives	0 for don't know, 1/3 for rarely, 2/3 for periodically, and 1 for continually
The time frame for performance targets	0 for no target, 1/3 for short term (less than one year), 2/3 for long term, and 1 for both
Rewards for production performance targets	0 for none, $\frac{1}{2}$ for manager only, and 1 for all staff
Human Resource Management Practices	
Employee promotion practices	0 for based on tenure, $\frac{1}{2}$ for based on effort and tenure, 1 is for based on only effort
Policy dealing with underperforming employees	0 for inaction, 1/3 for warning, 2/3 for warning and training, 1 for immediate removal from positions
Employees involved in making decisions	0 for no, and 1 for yes
Certain methods are used to select candidates	0 for no, and 1 for yes
Training programs for new hires	0 for no, and 1 for yes
Career development programs for employees	0 for no, and 1 for yes
Formal performance agreements at least annually	0 for no, and 1 for yes
Formal appraisals for non-managerial staff at least annually	0 for no, and 1 for yes
Formal appraisals for managerial staff at least annually	0 for no, and 1 for yes
Incentive programs (stock ownership, profit-sharing, gain-sharing, merit bonus) for non-managerial staff	0 for no, and 1 for yes
Incentive programs (stock ownership, profit-sharing, gain-sharing, merit bonus) for managerial staff	0 for no, and 1 for yes
Incentive programs (stock ownership, profit-sharing, gain-sharing, merit bonus) for all staff	0 for no, and 1 for yes