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Technological Frontiers and Post-2000 Productivity Growth in Canada

by Jianmin Tang and Weimin Wang

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Technological Frontiers and Post-2000 Productivity Growth in Canada

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Abstract

To better understand the movements in productivity during the post-2000 period in Canada, this paper applies the stochastic frontier framework to decompose each firm's multifactor productivity into two parts: its technological frontier and its technical efficiency. Change in the aggregate technological frontier refers to improvements in the productivity potential of the economy, or the maximum productivity of the economy if all firms are fully efficient. Aggregate technical efficiency reflects the economy's capacity to achieve that potential. Given that the drivers of these two sources of productivity growth are different, the decomposition sheds light on the factors that can account for changes in productivity. The empirical results show that changes in productivity since 2000 were mainly attributable to changes in the technological frontier. While an association is found between investments in research and development (R&D) and changes in the technological frontier, R&D accounts for only a small fraction of the change in the technological frontier over time.

Keywords: productivity slowdown, stochastic frontier, productivity frontier, technical efficiency

Executive summary

Multifactor productivity (MFP) declined in Canada from 2000 to 2009 and then recovered after. The movements in productivity since 2000 have attracted great attention from researchers and policy makers because productivity is important both for economic growth and for improvements in living standards.

This paper applies the stochastic frontier framework to decompose each firm's MFP into two parts: its technological frontier and its technical efficiency. Change in the aggregate technological frontier refers to improvements in the productivity potential of an economy, i.e., the maximum productivity of an economy if all firms are fully efficient. Aggregate technical efficiency reflects the economy's capacity to achieve that potential. The results of this decomposition can show whether the movements in productivity after 2000 in Canada were mainly the result of changes in the technological frontier and productivity potential or of changes in the technical efficiency.

This study uses the National Accounts Longitudinal Microdata File, which is a rich analytical dataset derived from various administrative sources. It contains major variables that are considered to be important for productivity analysis, including measures of gross output, labour input, physical capital (including information and communications technology capital), intangible capital (including research and development [R&D] and organizational capital), capacity utilization and intermediate inputs.

The results show that changes in productivity in Canada since 2000 were mainly attributable to changes in the technological frontier, and these changes cannot be largely explained by the factors most commonly associated with enabling greater productivity potential (e.g., investments in R&D).

To better understand changes in the technological frontier, the firms were divided into three groups: firms with higher-than-average MFP levels from 2000 to 2002, firms with lower-than-average MFP levels from 2000 to 2002 and firms that entered after 2002. Empirical results show that the overall movements of the technological frontier were mainly associated with the firms in the 2000-to-2002 cohort with high MFP levels.

1 Introduction

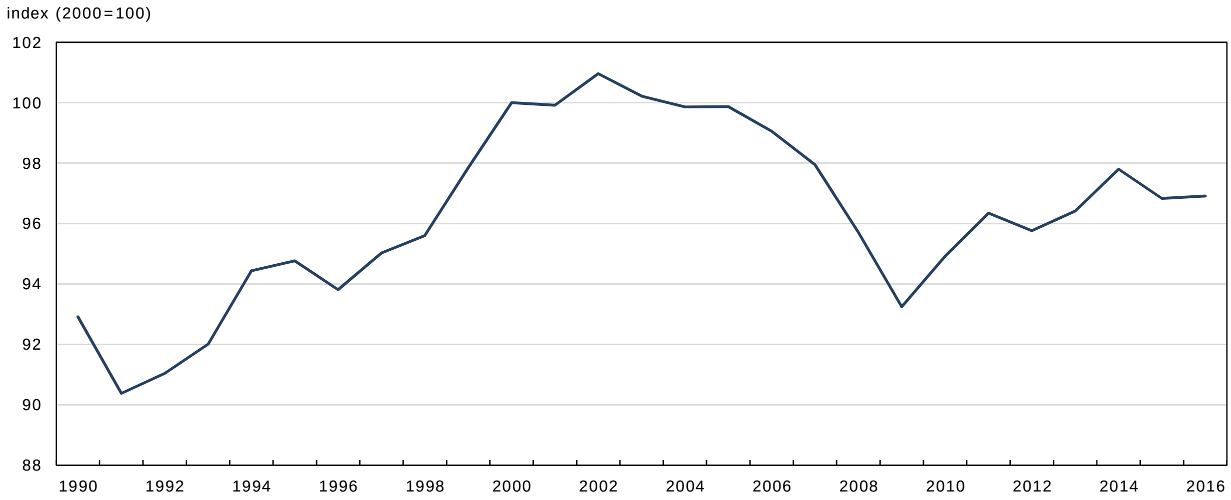
Multifactor productivity (MFP) in Canada started to decline in 2002, and the decline continued until 2009, with some recovery afterwards (Chart 1). This decline is not unique to Canada: it is widespread across many member countries of the Organisation for Economic Co-operation and Development, including other G7 economies. The productivity growth slowdown was dramatic and has attracted great attention from researchers and policy makers, as it has important implications for economic growth and prosperity.

However, despite extensive research, the causes of the productivity slowdown are still subject to debate (Murray 2017). Various arguments and counterarguments on both supply and demand sides have been put forward. On the supply side, Gordon (2012) argues that the productivity growth deceleration is the result of a slowdown in important innovation and diminishing returns from the innovation process. Consistent with Gordon's view is the suggestion that the decline is attributable to a waning of the productivity boom related to information and communications technology (ICT), which took place in the second half of the 1990s (e.g., Remes et al. 2018). However, Gordon's pessimistic view has been challenged (Sichel 2016). Byrne, Oliner and Sichel (2015) provided evidence that ICT-related technological progress has continued at a rapid pace since 2000. According to Syverson (2013), there has been no evidence that ICT-related productivity improvements have been exhausted.

Similar to the supply-side debate, the debate from the demand side has also gained significant traction. It has been asserted that weak aggregate demand, great uncertainty and financial market disruption because of the financial crisis, which led to the underutilization of production capacity and lower investments in productivity-enhancing activities (e.g., ICT and research and development [R&D]), could lead to a reduction in productivity (e.g., Remes et al. 2018). However, Fernald (2014) indicates that it is not likely that the post-2000 productivity slowdown was driven by demand, given that the decline started several years before the financial crisis. Some researchers even suggest that reverse causality might actually be at play, i.e., the expectation of lower future productivity and economic growth might cause weak demand (Blanchard, Lorenzoni and L'Huillier 2017).

Productivity is commonly measured as the Solow residual. It measures technological progress, but also reflects measurement errors in both output and inputs and captures any unmeasured factors that are important to productivity. As such, some commentators suggest that mismeasurement associated with the digital economy might play a role in the productivity slowdown. It has been suggested that current output estimates do not fully capture the services provided through ICT and other related technologies. However, subsequent research has shown that the measurement issue was not as important of a factor (e.g., Byrne, Fernald and Reinsdorf 2016; Ahmad and Schreyer 2016; Syverson 2016; Gu 2018).

Chart 1
Multifactor productivity in the Canadian business sector, 1990 to 2016



Source: Statistics Canada, table 36-10-0208-01.

There has been no strong empirical evidence of what caused the slowdown in productivity growth after 2000. This paper continues to search for answers. The National Accounts Longitudinal Microdata File (NALMF)—a rich analytical dataset derived from various administrative sources—was used to systematically study the causes of the productivity slowdown in Canada. Major factors that are considered to be the most important for productivity were considered simultaneously, including firm age; foreign ownership; industry structure; capacity utilization; and investments in R&D, ICT and intangibles.

Unlike most of the literature that focuses on actual productivity directly and implicitly assumes that all firms are efficient, this paper applies the stochastic frontier production framework to decompose productivity into the components of technological change and technical efficiency. Technological change measures productivity potential (or the maximum level of productivity under full efficiency), while technical efficiency reflects the ability and capacity to achieve that potential. Variations in efficiency could arise because of variations in capacity utilization over the business cycle or because of differences in managerial practices across firms that are influenced by incomplete markets; asymmetric information; different management incentive payment systems; and different cultural beliefs, traditions and expectations. In addition, they may be the result of firm-level differences in investments in efficiency-enhancing technologies, such as ICT.

Importantly, this decomposition facilitated an analysis to help better understand the determinants of actual productivity. The factors that affect the technological frontier are different from those that influence technical efficiency. This separation makes it possible to link factors directly to one of the two components.

The rest of this paper is organized as follows: Section 2 describes the stochastic frontier model, the factors that are important for technological change and technical efficiency, and the data. Empirical results and implications are discussed in Section 3. Section 4 examines trends in the technological frontier of high- and low-productivity firms in the 2000-to-2002 cohort and in that of firms that entered after 2002. Section 5 concludes.

2 Methodology and data

This paper decomposes actual productivity into technological change and technical efficiency based on the stochastic frontier model that was pioneered by Aigner, Lovell and Schmidt (1977).[1] Technological change refers to improvements in the productivity potential of the economy, i.e., the maximum productivity of the economy if all firms are fully efficient. In the stochastic frontier framework, this maximum productivity is called the technological frontier. The technological frontier is mainly driven by internal technological or innovative capacity, which feeds on a firm's own past and current investments in R&D (Aghion and Howitt 1992). Therefore, after external factors are controlled for, the technological frontier of a firm reflects its past and current internal R&D. Some other variables may also have an impact on the technological frontier of a firm—the first being foreign ownership. Generally, foreign-controlled firms in Canada are significantly more productive than Canadian-controlled firms after other factors are controlled for. The foreign ownership productivity advantage is real and significant in Canada. It is generally believed that this advantage arises because foreign-controlled firms in Canada have access to the advanced technologies and superior management practices of their parent firms (Rao, Souare and Wang 2009; Tang and Rao 2003). The second factor is industry–year dummies. Industry–year dummies are introduced to control for all time-variant and time-invariant industry-specific effects. For example, they capture industry-specific demand shocks, spillover effects (such as those from external R&D) and effects from changes in the business environment, including competition and business dynamism (e.g., entry and exit).

Technical efficiency reflects the economy's ability to be at the technological frontier. Technical efficiency has to be maintained or enhanced through the adoption of technology and investments in firm-specific human, knowledge and business organizational capital. Technical efficiency can also be affected by changes in the utilization rate of inputs when demand conditions fluctuate. In this paper, technology adoption was measured by investments in ICT, including software. The adoption of ICT allows firms to more efficiently organize their inputs, manage their inventories and conduct international business activities (Biagi 2013).

Investments in skills and better management practices are represented by investments in intangible, firm-specific human, knowledge and business organizational capital. Intangible capital enables efficient business execution (e.g., Battisti, Belloc and Del Gatto 2012). Corrado, Hulten and Sichel (2009) showed that these intangibles played a significant role in economic growth in the United States. Likewise, Baldwin, Gu and Macdonald (2012) obtained similar results for Canada. Furthermore, Ilmakunnas and Piekkola (2014) also linked investments in intangibles to higher productivity performance in Finland.

Firm-specific skills and organizational capital may also be improved through learning by doing, especially for young firms or start-ups. Therefore, a dummy variable is used to reflect the potential efficiency deficit facing young firms. Young firms are generally believed to be less efficient than established firms, as it takes time for young firms to learn their markets, establish supplier and distribution networks, and develop scale. According to Liu and Tang (2017), entrants take about five years to become as productive as incumbents.

Capacity utilization is used to capture the influence of changes in demand conditions on technical efficiency. An unexpected change in demand conditions affects the utilization of production capacity as firms are unable to adjust installed machines or even their workforce to suit the new demand. For example, a significantly lower demand than expected will lead to the underutilization of production capacity, which means that workers may not work to their full capacity and machines may sit idle more often than before. This leads to inefficiency. Basu and Kimball (1997) showed that changes in capacity utilization could explain up to 60% of short-run economic fluctuation. Baldwin, Gu and Yan (2013) showed that the Canadian manufacturing sector experienced excess

1. Kumbhakar and Lovell (2000) provide an excellent introduction to stochastic frontier analysis.

capacity after 2000, with a decline in capacity utilization in 16 of the 20 manufacturing industries. This suggests that the development of excess capacity was mainly attributable to the large decline in exports as a result of the change in the trade environment during that period.

The stochastic frontier regression model can be written as

$$\begin{aligned}\ln(\text{gross output}) &= \alpha_0 + \alpha_L \ln(\text{labour}) + \alpha_K \ln(\text{capital}) + \alpha_M \ln(\text{intermediate}) \\ &+ \beta_R \ln(\text{R\&D}) + \boldsymbol{\beta}_Z \mathbf{Z} + v - u, \qquad \text{with} \quad u = \gamma_0 + \boldsymbol{\gamma}_X \mathbf{X}\end{aligned} \tag{1}$$

where $\mathbf{Z}$ is a vector of variables controlling for the effects of external factors on the technological frontier, v is a random error term reflecting the stochastic nature of the technological frontier, u is a measure of technical inefficiency or the distance to the production possibility frontier,[2] and $\mathbf{X}$ is a vector of the covariates that may affect technical efficiency.

The data used in this paper come from the NALMF. The data cover all industries from 2000 to 2014. The NALMF's source data come from tax files (T2 Corporation Income Tax Return, T4 Statement of Remuneration Paid and PD7 Payroll Account Deductions); the Business Register; and the Survey of Employment, Payrolls and Hours. The T2 Corporation Income Tax Return form can be used to derive a firm's gross output, physical capital stock and intermediate inputs, as well as its ICT capital stock, R&D investment and spending on intangibles. R&D capital stock and intangible capital stock are then derived using the perpetual inventory method. The other source data provide payroll and employment information, foreign ownership indicators, and the year a firm was founded.

Nominal variables need to be deflated for over-time comparisons. Because of the lack of deflators at the firm level, detailed industry-level deflators from the KLEMS database were used.[3] The deflator for R&D is the implicit price index for R&D investments derived from Statistics Canada table 36-10-0098-01.[4]

Tangible capital stock includes assets associated with machinery, equipment and buildings. It includes ICT stock, but excludes intangible assets and R&D stocks. The R&D stock for each firm is estimated from real R&D investments using the perpetual inventory method, assuming a capital depreciation rate of 15%. R&D expenditures were derived from the Scientific Research and Experimental Development Program data included in the T2 Corporation Income Tax Return. Following Corrado, Hulten and Sichel (2005, 2009), spending on intangible assets consists of non-scientific innovative properties (architect fees) and economic competencies that include organizational capital (20% of director and management salaries plus consulting fees), brand equity (60% of advertising) and firm-specific human capital (training). These six items were obtained directly from the General Index of Financial Information included in the T2 Corporation Income Tax Return. Nominal intangible spending was deflated using an industry-level implicit price deflator for intermediate inputs (from KLEMS). The perpetual inventory method was used for estimating intangible capital stock from real intangible spending, assuming a 15% depreciation rate. Total capital stock equals the sum of all tangible, intangible and R&D capital stocks.

A dummy variable was introduced to determine whether young firms were more or less efficient than established ones. According to Liu and Tang (2017), entrants in Canada take about five years to become as efficient as incumbents. Therefore, the dummy variable equalled 1 if a

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2. Following Kumbhakar, Ghosh and McGuckin (1991), Reifschneider and Stevenson (1991), and Battese and Coelli (1995), u is specified as a non-negative error term that is independently and normally distributed with a nonzero mean and a truncation point at 0.
3. For a description of the KLEMS (capital, labour, energy, materials and services inputs) database for Canada, see Baldwin, Gu and Yan (2007).
4. Formerly CANSIM table 031-0007.

firm was less than six years old and equalled 0 otherwise. Lastly, capital use intensity was calculated with adjustment for the input substitution effect[5] as an indicator of capacity utilization.

For the estimation, the sample was restricted to include only firms with an average of 10 or more employees over the sample period. The average number of employees per firm was used instead of the number of employees in each year to avoid truncated observations for the firms in the sample. The restricted sample represents 88% and 83% of gross output and employment in Canada, respectively. With this restriction, there were nearly 1.9 million observations for the entire sample period (Table 1).

Table 1
Distribution of sample observations (firms with 10 or more employees in the business sector)

NAICS industry	2000	2005	2009	2014	2000 to 2014
			number of observations		
Crop and animal production	738	727	716	572	10,772
Forestry and logging	730	714	625	492	9,715
Fishing, hunting and trapping	61	77	77	68	1,096
Support activities for agriculture and forestry	358	423	426	406	6,148
Oil and gas extraction	204	226	216	178	3,139
Mining and quarrying (except oil and gas)	304	285	279	266	4,257
Support activities for mining, and oil and gas extraction	688	786	853	736	11,425
Utilities	147	219	186	182	2,840
Construction	11,625	12,986	13,608	13,968	197,518
Food manufacturing	2,139	2,084	1,959	1,856	30,174
Beverage and tobacco manufacturing	162	148	145	177	2,304
Textile and textile product mills	583	505	377	314	6,653
Clothing, leather and allied product manufacturing	1,217	947	624	411	12,071
Wood product manufacturing	1,586	1,571	1,443	1,251	22,150
Paper manufacturing	448	395	324	262	5,351
Printing and related support activities	1,180	1,135	1,011	837	15,693
Petroleum and coal product manufacturing	81	80	51	40	935
Chemical manufacturing	789	734	685	645	10,725
Plastics and rubber products manufacturing	1,202	1,176	1,074	1,026	16,783
Non-metallic mineral product manufacturing	716	741	676	616	10,409
Primary metal manufacturing	322	318	304	265	4,553
Fabricated metal product manufacturing	3,116	3,148	2,951	2,762	45,426
Machinery manufacturing	1,979	2,004	1,884	1,750	28,777
Computer and electronic product manufacturing	869	802	745	616	11,476
Electrical equipment, appliance and component manufacturing	461	459	425	385	6,561
Transportation equipment manufacturing	930	904	835	721	12,704
Furniture and related product manufacturing	1,334	1,384	1,261	1,100	19,418
Miscellaneous manufacturing	1,022	1,117	1,033	965	15,706
Wholesale trade	12,094	11,856	11,441	10,555	173,753
Retail trade	18,902	20,072	19,845	18,968	294,953
Transportation and warehousing	5,625	5,791	5,546	5,406	84,463
Information and cultural industries	1,963	1,954	1,891	1,952	29,269
Finance, insurance, real estate and company management	7,206	7,257	7,323	6,777	107,248
Professional, scientific and technical services	7,475	8,227	8,215	7,592	120,297
Administrative and support, waste management and remediation services	5,440	6,528	7,021	6,982	99,274
Arts, entertainment and recreation	2,400	2,879	2,920	2,844	42,100
Accommodation and food services	17,559	20,062	21,386	22,742	310,793
Other services (except public administration)	5,360	6,789	7,752	8,053	106,460
All industries	119,015	127,510	128,133	124,738	1,893,389

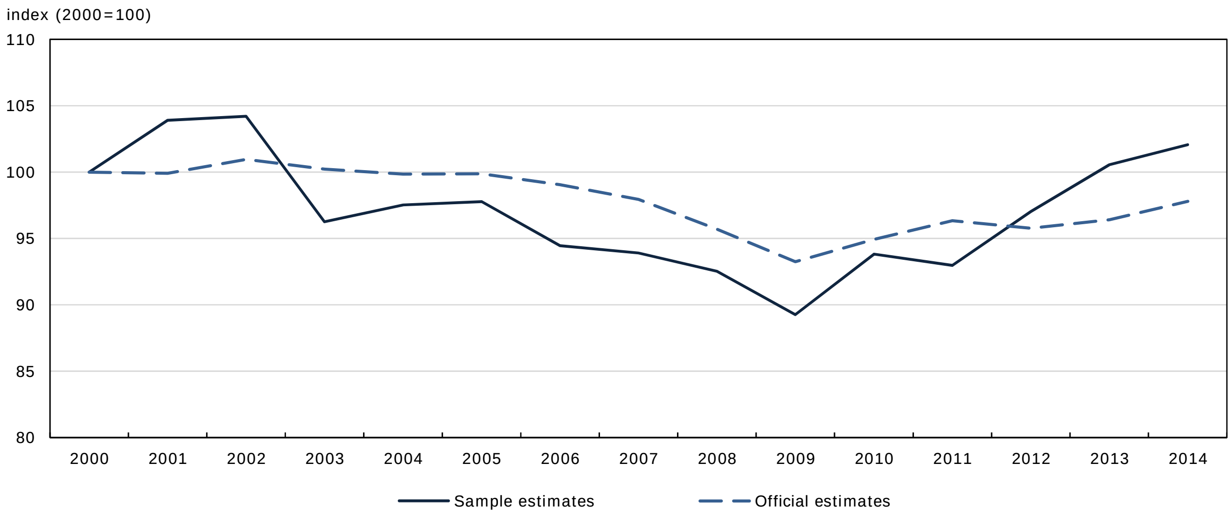
Note: NAICS: North American Industry Classification System.
Source: Statistics Canada, authors' compilation based on data from the National Accounts Longitudinal Microdata File.

5. The rationale and measurement of capacity utilization are available upon request.

There are two reasons why small firms were excluded. First, the derivation of the major variables necessary for productivity analysis involves the use of fields in the source data that are not mandatory. For smaller firms with less economic activity, these data fields are often left blank. The second reason is technical—it is time consuming to use all firms for the estimation, as there were more than 9 million observations before the exclusion.[6]

Despite this exclusion, the estimates of aggregate MFP based on the sample used for the estimation of (1) track the movements of the official estimates of MFP for the business sector closely (Chart 2). The sample-based MFP measure aggregated firm-level MFP using Domar weights. These Domar weights were calculated as the ratio of a firm's nominal gross output over the business sector's nominal value added. The MFP at the firm level was calculated as a residual of gross output minus contributions from labour, capital and intermediate inputs. The output elasticities with respect to all inputs were obtained using ordinary least squares (OLS), controlling for industry–year dummies.[7]

Chart 2
Sample-based and official multifactor productivity estimates in the business sector



Sources: Statistics Canada, table 36-10-0208-01 for the official estimates and authors' compilation based on data from the National Accounts Longitudinal Microdata File for the sample estimates.

The movements of the two series were generally consistent. The series based on the sample used for estimation was more volatile than the official one—both the decline after 2002 and the recovery after 2009 were more dramatic. The difference may be attributable to a number of factors. First, the elasticity of output with respect to inputs used in calculating MFP for the sample used in the estimation was regression-based and fixed over the estimation period, while that for the official estimates was based on growth accounting and was time varying. Second, small firms were excluded from the sample. Third, the MFP calculation for the sample used in the estimation did not adjust for capital quality and labour composition, while the official MFP estimates did. Lastly, the MFP calculation for the sample used in the estimation was Domar-aggregated at the firm level. The official estimates were Domar-aggregated from industry-level data. These industry-level data came from a greater number of data sources than are used in the NALMF.

6. It has been proven that the regression results were similar with and without small firms.
7. When estimating MFP, the sum of the output elasticities of labour, capital and intermediate inputs is 0.99. Therefore, measured MFP is not significantly influenced by decreasing or increasing returns to scale, in line with the official aggregate MFP estimate.

3 Estimation results

The stochastic frontier estimation results are reported in Table 2. The first regression is for the whole sample period and for all firms with 10 or more employees. For the technological frontier, the results show that R&D investments and foreign ownership are important for raising productivity potential. For inefficiency, all variables were found to be negative and highly significant, meaning that firms with more investments in ICT and intangibles, as well as young firms, tend to be closer to their technological frontiers.[8] Furthermore, as expected, capacity utilization is positively associated with technical efficiency.

Interestingly, the estimated coefficients of all variables based on the stochastic frontier model (regression [1]) in Table 2) were similar to the results of some traditional regressions.[9] Implicitly, the similarity is a robustness check of the results from the stochastic frontier estimation.[10]

Regressions (2) and (3) in Table 2 are for the sub-periods from 2009 to 2014 and from 2000 to 2009, respectively. The purpose was to determine whether the effect of any of those factors changed significantly over these two sub-periods. Overall, there were no significant changes for R&D, foreign ownership, ICT and intangibles. However, the efficiency advantage of young firms over established firms was greater after the financial crisis. This is an interesting result, and may be because only high-efficiency and productive firms can enter the market after the financial crisis.

Regressions (4) and (5) are for manufacturing and non-manufacturing firms, respectively. These two sets of results are generally similar. However, the impact of R&D and foreign ownership on manufacturing firms was smaller than on non-manufacturing firms. The same is true for the effect of ICT on technical efficiency. In addition, the efficiency advantage of young firms was larger in manufacturing than in non-manufacturing.

Given the general consistency across all columns in Table 2, the discussion and analysis to follow will be based on the estimation results in Column 1 of Table 2.

8. The finding that young firms are more productive than established firms was surprising. Some literature shows that young firms are generally less productive than established firms (Tang 2014; Liu and Tang 2017). One possible explanation may be that firms with fewer than 10 employees were excluded from the study sample. Many small firms are young firms that tend to be less productive. This finding is consistent with Tang and Van Assche (2017), who also showed that young firms were more productive than established firms when only relatively large firms were included in the sample.
9. These regressions include OLS regressions with robust standard errors, OLS regressions with clustered standard errors and Levinsohn–Petrin regressions for addressing possible endogeneity or simultaneity issues (Levinsohn and Petrin 2003). The results are available upon request.
10. People may argue that some $\mathbf{X}$ variables may affect the productivity frontier and that some $\mathbf{Z}$ variables may affect technical efficiency. This may be true; however, the similarity in results between OLS and stochastic frontier estimation suggests that the results will not change when an alternative stochastic frontier model is used. In fact, this was tested and, when the foreign ownership dummy variable was shifted from $\mathbf{Z}$ to $\mathbf{X}$ and the intangible variable was shifted from $\mathbf{X}$ to $\mathbf{Z}$ in Equation (1), the coefficients remained virtually the same.

Table 2
Stochastic frontier estimation of the production function

	Regression 1	Regression 2	Regression 3	Regression 4	Regression 5
	All firms 2000 to 2014	All firms 2009 to 2014	All firms 2000 to 2009	Manufacturing firms 2000 to 2014	Non-manufacturing firms 2000 to 2014
Technological frontier					
Labour (in log)					
Coefficient	0.2780 **	0.2921 **	0.2699 **	0.2367 **	0.2821 **
Standard error	0.0003	0.0005	0.0004	0.0007	0.0003
Tangible capital (in log)					
Coefficient	0.0647 **	0.0623 **	0.0664 **	0.0716 **	0.0643 **
Standard error	0.0002	0.0003	0.0002	0.0005	0.0002
Intermediate inputs (in log)					
Coefficient	0.6455 **	0.6361 **	0.6500 **	0.6814 **	0.6410 **
Standard error	0.0002	0.0004	0.0003	0.0005	0.0003
R&D stock (in log)					
Coefficient	0.0049 **	0.0044 **	0.0053 **	0.0013 **	0.0068 **
Standard error	0.0001	0.0001	0.0001	0.0001	0.0001
Foreign-owned					
Coefficient	0.2025 **	0.2140 **	0.1960 **	0.1106 **	0.2279 **
Standard error	0.0015	0.0021	0.0020	0.0021	0.0018
Industry dummy variables	Yes	Yes	Yes	Yes	Yes
Year dummy variables	Yes	Yes	Yes	Yes	Yes
Year by industry dummy variables	Yes	Yes	Yes	Yes	Yes
Inefficiency					
Ratio of ICT to total capital stock					
Coefficient	-0.2600 **	-0.2564 **	-0.2635 **	-0.1418 **	-0.2663 **
Standard error	0.0018	0.0030	0.0022	0.0064	0.0019
Ratio of intangibles to total capital stock					
Coefficient	-0.2242 **	-0.2279 **	-0.2235 **	-0.1974 **	-0.2271 **
Standard error	0.0013	0.0021	0.0016	0.0033	0.0014
Young firms					
Coefficient	-0.0087 **	-0.0183 **	-0.0039 **	-0.0291 **	-0.0056 **
Standard error	0.0006	0.0011	0.0007	0.0013	0.0007
Capacity utilization					
Coefficient	-0.0408 **	-0.0450 **	-0.0385 **	-0.0413 **	-0.0410 **
Standard error	0.0004	0.0008	0.0005	0.0008	0.0005
Constant	Yes	Yes	Yes	Yes	Yes
Number of observations	1,893,389	764,016	1,257,506	277,869	1,615,520

** significantly different from reference category ($p < 0.01$)

Note: ICT: information and communications technology; R&D: research and development.

Source: Statistics Canada, authors' compilation based on data from the National Accounts Longitudinal Microdata File.

Elasticities of technological change or technical efficiency with respect to each factor were estimated to determine their sensitivity to control factors. The estimated elasticities are reported in Table 3. The results show that doubling R&D—for example—would lead to a 0.5% increase in the technological frontier. Furthermore, foreign-owned firms are—on average—20.3% more productive than a domestic firm. For technical efficiency, if the ratio of ICT to total capital and the ratio of intangibles to total capital are doubled, efficiency would increase by 1.8% and 2.7%, respectively. In addition, young firms have a 0.9% efficiency advantage over established firms, and a 10% increase in capacity utilization would increase efficiency by 0.4%. Given these elasticities, even when all firms doubled their R&D, ICT and intangible capital stock over the period from 2002 to 2009, the drop in MFP over the period can be reduced by 5 percentage points only, leaving a large portion of the decline unexplained.

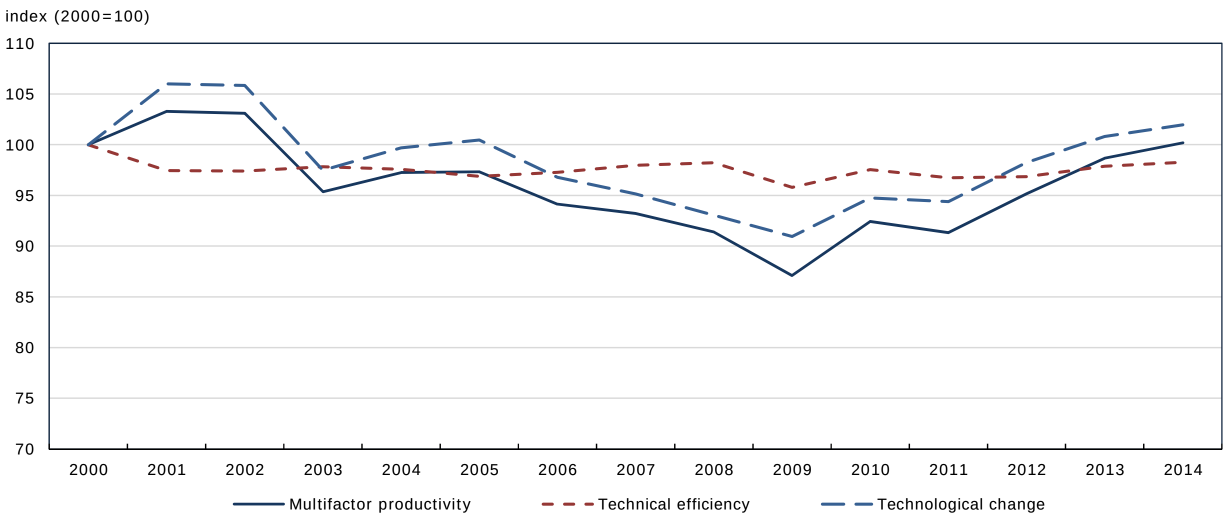
Table 3
Average elasticities of technological change or technical efficiency with respect to their factors

Factor	Elasticity
	coefficient
Technological change with respect to its factors	
Research and development	0.0049
Foreign-controlled	0.2025
Technical efficiency with respect to its factors	
Ratio of information and communications technology to total capital	0.0181
Ratio of intangibles to total capital	0.0272
Young firm	0.8698
Capacity utilization	0.0408

Source: Statistics Canada, authors' compilation based on data from the National Accounts Longitudinal Microdata File.

Changes in MFP, technological frontier and technical efficiency at the firm level were aggregated using Domar weights. The indexes of the business-sector MFP, technological frontier and technical efficiency are depicted in Chart 3, which shows that the movement of MFP was largely driven by the movement of the technological frontier, while technical efficiency was relatively stable over the whole period.

Chart 3
Multifactor productivity, technological change and technical efficiency in the business sector



Source: Statistics Canada, authors' compilation based on data from the National Accounts Longitudinal Microdata File.

4 The movement of high-productivity and low-productivity cohorts

To shed more light on the productivity slowdown, firms in the 2000-to-2002 cohort were divided into two groups.[11] The high-productivity group consisted of firms with MFP levels higher than the corresponding industry averages over the period from 2000 to 2002, and all of the remaining firms in the cohort were in the low-productivity group. All firms that appeared after 2002 were considered new entrants.

Chart 4 shows the trends in the technological frontiers of the three groups of firms. The technological frontier increased across the entire sample for the low-productivity cohort, but declined for the other two groups until 2009, implying that the retreat of the technological frontier

11. The period from 2000 to 2002 was chosen because productivity started to decline after 2002, as shown in Chart 2.

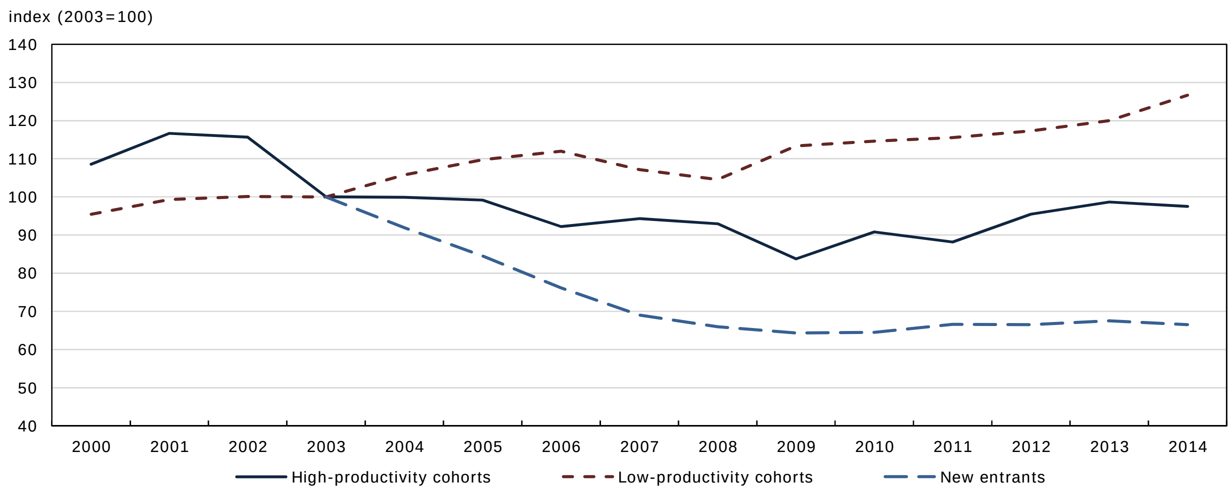
was driven by the high-productivity cohort and the new entrants. As shown in Table 4, the aggregate technological frontier dropped by 7.0% from 2003 to 2009. The contributions of the high-productivity cohort, the low-productivity cohort and the new entrants were -8.4, 4.9 and -3.5 percentage points, respectively. The technological frontier fully recovered after 2009, and the corresponding contributions were 7.0, 4.2 and 0.7 percentage points. These results suggest that the retreat of the technological frontier was mainly driven by the high-productivity firms in the 2000-to-2002 cohort.

Table 4
Contribution of high-productivity and low-productivity cohorts and new entrants to growth in technological frontier

	2003 to 2009	2009 to 2014
	percent	
Change in technological frontier	-7.0	11.9
	percentage points	
Contribution		
High-productivity cohort	-8.4	7.0
Low-productivity cohort	4.9	4.2
Entrants after 2002	-3.5	0.7

Source: Statistics Canada, authors' compilation based on data from the National Accounts Longitudinal Microdata File.

Chart 4
Trends in the technological frontiers of high-productivity and low-productivity cohorts and new entrants in the business sector



Note: New entrants entering the business sector in 2003.
Source: Statistics Canada, authors' compilation based on data from the National Accounts Longitudinal Microdata File.

5 Conclusion

By decomposing actual productivity into technological frontier (or technology-related productivity potential) and technical efficiency, the empirical results of this study show that the decline in Canada's productivity from 2000 to 2009 and the subsequent recovery were largely associated with changes in the technological frontier.

This paper shows that (1) R&D investments and foreign-controlled firms in particular played important roles in supporting the technological frontier, while industrial structure played a minor negative role; (2) ICT and intangibles played a positive role in supporting technical efficiency.

In addition, this study demonstrates that movements in productivity in Canada after 2000 were largely associated with the high-productivity firms in the 2000-to-2002 cohort. This evidence is consistent with the findings in the literature for the Canadian manufacturing sector. The post-2000 productivity decline in the Canadian manufacturing sector was mainly the result of a decline in the productivity of large firms (Tang 2017) or exporters (Baldwin, Gu and Yan 2013). However, Baldwin, Gu and Yan (2013) also claimed that at least half of the productivity decline was attributable to the pro-cyclical nature of productivity growth arising from capacity utilization, but this was not the case in this paper. A future study of the causes of the weak productivity performance of large and exporting firms may shed more light on the productivity slowdown in Canada.

It is important to note that technological frontier and frontier firm are different concepts. The former is associated with each firm's technological potential, while the latter refers to high-productivity firms and is often used to examine the productivity dispersion between frontier and non-frontier firms.[12] Gu, Yan and Ratté (2018) found that the relative labour productivity level of frontier-to-non-frontier firms in Canadian manufacturing decreased from 2000 to 2005 and increased thereafter, implying that the aggregate productivity growth was mainly driven by frontier firms. This is generally consistent with the findings in this paper.

12. See Gu, Yan and Ratté (2018) and Andrews, Criscuolo and Gal (2015).

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