Frontier Firms, Productivity Dispersion and Aggregate Productivity Growth in Canada

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Abstract

Labour productivity growth in the business sector in Canada fell off after 2000. This article examines how innovation, innovation diffusion across firms, and business dynamism affected the productivity slowdown. The article found that both innovation and diffusion of innovation declined in Canada after 2000, contributing to the decline in labour productivity growth in that period. However, their relative contribution to the productivity slowdown is sensitive to the methods adopted. The results from a productivity decomposition into contributions of frontier firms (defined as the top 10 per cent most productive firms in an industry) and non-frontier firms show that the slowdown in the diffusion of innovation is a main source of the productivity slowdown after 2000. In contrast, the results from a stochastic frontier analysis show that the decline in innovation is the main source of the productivity slowdown after 2000. Finally, this article found that resource reallocation declined in Canadian firms after 2000, contributing to the decline in aggregate labour productivity growth.

Productivity growth has slowed in Canada and other developed countries since the early 2000s. For example, business sector labour productivity in the United States had been growing at an average rate of 2.1 per cent, year over year. Then, in 2004, the productivity growth rate began to decline, falling to an average of 1.2 per cent per year from 2004 to 2014 (Manyika *et al.*, 2017; Murray, 2018). Business sector labour productivity growth in Canada fell off after 2000, from 1.7 per cent per year in the period from 1980 to 2000 to 1.0 per cent per year in the period from 2000 to 2015 (Gu 2018).[2] This decline in productivity growth also occurred in other developed countries. Labour productivity growth after 2004 has been the weakest on record in most OECD countries since 1950 (OECD, 2015).

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2 Labour productivity is defined as real value added per hour worked. The growth estimates are obtained from Statistics Canada Table 36-10-0211-01 for multifactor productivity and related variables in the aggregate business sector and major subsectors.

Previous studies have identified a number of explanations for this trend. While the slowdown in productivity growth after 2000 is partly the result of cyclical factors—such as slow output growth and the burst of the dot-com bubble in the early 2000s, and the 2008–2009 global financial crisis—a number of structural factors have also been suggested as explanations for this slowdown (Baily and Montalbano, 2016; Cette, Corde and Lecat, 2017; OECD, 2015; Murray, 2018). These structural factors include a slower pace of innovation and technological progress, a slowdown in innovation diffusion, changes in competitive intensity, a decline in business dynamism, and resource misallocation—possibly caused by the sharp decline in real interest rates.

This article examines the role of structural factors in the post-2000 productivity growth slowdown in Canada. First, this article looks at the role that innovation in frontier firms and innovation diffusion from frontier firms to non-frontier firms played in the decline in productivity growth after 2000. According to Gordon (2016), the slow pace of innovation caused the productivity slowdown in developed countries, and current technological advances such as digital technologies, robots and cloud computing are not important enough to drive strong productivity growth. He argues that historical innovations such as steam engines and electricity had far greater impacts on productivity growth than current technological developments. As an alternative explanation for the productivity slowdown, the OECD (2015) presented empirical evidence that the main cause of the productivity slowdown was not a slowing pace of innovation by frontier firms, but rather a slowing pace of innovation diffusion from frontier firms to non-frontier firms in the early 2000s (Andrews, Criscuolo and Gal, 2015; OECD, 2015).

Second, this article examines the role of changes in business dynamism and changes in resource allocation in the productivity slowdown. Previous studies for Canada, the United States and other developed countries found evidence of declining business start-ups, declining gross job creation and destruction, and rising resource misallocation in the 2000s (Decker *et al.* (2016) for the United States; Cao *et al.* (2017) and Macdonald (2014) for Canada). However, the extent to which changes in business dynamism and changes in resource allocation contributed to the productivity slowdown is not known.

To assess the relative impact of innovation and innovation diffusion on the productivity slowdown, this article divides all firms in an industry into frontier and non-frontier firms in terms of labour productivity levels, and decomposes aggregate productivity growth into contributions from frontier firms and non-frontier firms. Frontier firms are defined as the top 10 per cent most productive firms in an industry. Non-frontier firms include all other firms. Productivity growth of frontier firms is used to assess the pace of innovation over time. Productivity growth of non-frontier firms is used to assess the pace of innovation diffusion over time (Andrews, Criscuolo and Gal, 2015).

To assess the robustness of results on the roles of innovation and diffusion of innovation in the productivity slowdown from this accounting approach, a stochastic fron-

tier production function approach was also used as an alternative. The stochastic frontier production function approach decomposes productivity growth into technical change and technical efficiency change. Technical change is calculated as the productivity growth of the most productive firms that form the production frontier, and technical efficiency change is calculated as the change in the productivity gap between non-frontier firms and the most productive firms over time. It is a measure of non-frontier firms' ability to catch up to frontier firms. For the purpose of this article, technical change is interpreted as the pace of innovation in frontier firms, and technical efficiency change represents the rate of innovation diffusion from frontier firms to non-frontier firms.

Previous studies have examined the productivity growth difference between frontier and non-frontier firms, and its implication for aggregate productivity growth. The OECD (2017) found that the dispersion in productivity growth between the best-performing and the worst-performing firms increased in a number of OECD countries, including Canada, since 2000. Andrews, Criscuolo and Gal (2015) found that the productivity growth of global frontier firms remained robust after 2004, when aggregate productivity growth in advanced economies began to slow. This was interpreted as evidence that the main source of the productivity slowdown was not a slowing pace of innovation by the most globally advanced firms, but rather a slowing pace at which innovations spread throughout the economy.

Haldane (2017) examined productivity dispersion in the United Kingdom and concluded that the decline in productivity growth in that country after the financial crisis, compared with that of the early 2000s, was the result of the poor productivity growth of non-frontier firms. The productivity growth of frontier firms in the United Kingdom was robust after the financial crisis. Cette, Corde and Lecat (2017) found that robust productivity growth of frontier firms in France increased after 2000, and that the pace of innovation did not decline in the 2000s. However, no evidence was found that innovation diffusion from frontier firms to non-frontier firms slowed after 2000 in France.

Most previous studies focused on productivity dispersion and productivity growth of frontier and non-frontier firms in the 2000s, and used this information to provide evidence on the role of innovation and diffusion in aggregate productivity growth in the 2000s. But, as Andrews, Criscuolo and Gal (2015) noted, this data limitation with short time series makes it difficult to address the issue of whether productivity growth of frontier and non-frontier firms slowed after 2000, compared with the period before 2000. Therefore, evidence for the 2000s cannot be used alone to examine the role of innovation and innovation diffusion in the post-2000 productivity slowdown. This article addresses this data limitation by using data over a longer period, including data for both before and after 2000, and constitutes the first Canadian evidence on productivity growth of frontier and non-frontier firms. This provides direct evidence on the role of innovation and innovation diffusion in aggregate productivity growth slowdown in the 2000s.

The article is organized as follows. Section one presents the data used for the analysis. Section two presents productivity dispersion of frontier and non-frontier firms, and the firms' contributions to aggregate productivity growth. Section three uses the stochastic frontier approach to decompose productivity growth into technical change (identified as innovation in frontier firms) and technical efficiency change (identified as innovation diffusion from frontier to non-frontier firms). Section four examines the effect of resource reallocation on productivity growth over time, and its contribution to the decline in aggregate productivity growth after 2000. Section five concludes.

Data Sources

The data used for this article are from Statistics Canada's T2–LEAP longitudinal firm-level database.[3] This database was created by linking two administrative databases: the Longitudinal Employment Analysis Program (LEAP) file and the Corporate Tax Statistical Universal File (T2).

The LEAP file is a database that includes all employers in Canada, both incorporated and unincorporated, that register a payroll deduction account with the Canada Revenue Agency (CRA). The LEAP file contains longitudinal firm identification numbers, which are used to examine the growth, entry and exit of firms. The firms in the LEAP file have been assigned to industries according to the North American Industry Classification System (NAICS).

The LEAP file was linked to the T2 file, which includes all incorporated firms that file a T2 tax return with the Canadian Revenus Agency. The linked T2–LEAP file provides data on total sales, payroll, net income, and assets for all incorporated firms in Canada. A derived measure of average employment, called average labour units (ALUs), is estimated and added to the file. A firm's ALUs are calculated as the ratio of the firm's total payroll to average annual worker wages in that firm's industry, size class, and province.[4]

This article focuses on incorporated businesses in Canada. Businesses in the agriculture, forestry and fishing, health, and education sectors are excluded since measures of output, inputs and productivity are less reliable for some of those sectors. The examined incorporated businesses comprise the non-farm market sector in Canada. The article examines the non-agriculture or non-farm market sector's labour productivity and multifactor productivity (MFP).[5] Labour productivity is defined as real gross output per worker. MFP is defined as gross output per unit of

3 Previous studies (e.g., Baldwin and Gu, 2011; Gu and Lafrance, 2014) have used the T2–LEAP file to study the productivity dynamics of the non-manufacturing sectors.

4 The database was cleaned for outliers, using a method based on the outliers principle developed by Tukey (1977). This method deletes values located beyond quartile 1 (and 3), which are less (and more) than three times the interquartile spread of labour productivity levels at the three-digit NAICS industry classification level in a year. About 1 per cent of the observations were classified as outliers using this method, and they were removed from the analysis in this article.

5 Because of data issues, forestry and fishing was also excluded from the non-farm market sector.

combined capital, labour and intermediate inputs. Capital input for measuring MFP is estimated as the book values of tangible assets, deflated by an industry capital stock price index. Intermediate input is measured as sales minus the sum of payroll and capital income (estimated as net income before taxes).

Labour productivity, output and employment are available for the period from 1991 to 2015. MFP and related output and input measures are available for the period from 2000 to 2015 as values of tangible assets, and intermediate inputs are available only after 2000.

Labour productivity (gross output per worker) of the non-farm market sector — derived from the T2–LEAP microdata file — shows similar trends to labour productivity (gross output per hour worked) for the business sector, derived from the Statistics Canada industry productivity database. Both estimates of aggregate labour productivity growth declined after 2000. Aggregate labour productivity of the business sector derived from the industry productivity database declined from 2.96 per cent per year for the 1991-2000 period to 0.74 per cent per year for the 2000-2015 period. Aggregate labour productivity growth of the non-farm market sector derived from the T2–LEAP file also showed a large decline after 2000—from 2.90 per cent per year to -0.07 per cent per year between the two periods.[6]

The post-2000 decline in labour productivity growth in Canada has been well documented, and numerous studies have focused on the causes of this large decline (e.g. Gu, 2018; Sharpe and Tsang, 2018). Those studies concluded that the rapid productivity growth in the 1990s can be traced to trade liberalization and the adoption of information and communications technology (ICT) in that period. The slow labour productivity growth after 2000 is related to slower growth in MFP, slower growth in demand, and a decline in the contribution of exporters and large multinational firms in the early 2000s (Baldwin, Gu and Yan, 2013; Rao and Li, 2013; Baldwin and Gu, 2004; Trefler, 2004). A decline in MFP growth in the mining sector caused by increased costs for the extraction of natural resources also contributed to the slow productivity growth in the 2000s (Gu, 2018).

Productivity Dispersion and Aggregate Productivity Growth

This section has two main objectives. First, it presents trends in the productivity growth of frontier and non-frontier firms. The productivity growth of frontier firms is commonly associated with innovation and technical progress. The productivity growth of non-frontier firms is associated with innovation diffusion from frontier firms to non-frontier firms, or catch-up of non-frontier firms to frontier firms. Second, this section decomposes aggregate productivity growth into contributions of frontier and non-frontier firms. The evidence on contributions of frontier and non-

6 After 2000, there is a large difference in growth rates in the two estimates of labour productivity growth. The sources of this difference may include the difference in industry coverage and the differences in labour unit measures.

frontier firms enables an assessment of the roles of innovation in frontier firms and innovation diffusion from frontier to non-frontier firms on aggregate productivity growth over time, and their contributions to the decline in productivity growth in Canada after 2000.

The analysis will focus on two periods: 1991–2000 and 2000–2015. Short-term changes in productivity can be caused by cyclical factors that arise from changes in the use of capital and output growth. This was the case in the early 2000s and the early 1990s (Baldwin, Gu and Yan, 2013). Focusing on these relatively long periods removes the effects of cyclical factors on productivity, and therefore allows the identification of structural factors — such as innovation and technological diffusion — on productivity growth.

Frontier firms are defined as the top 10 per cent most productive firms, in terms of labour productivity levels within the three-digit NAICS 2007 classification level. All other firms within a three-digit NAICS industry code are defined as non-frontier firms. There are a total of 87 industries in the non-farm market sector at the three-digit NAICS level of industry aggregation.

Productivity of Frontier and Non-frontier F'irms

This sub-section presents the productivity of frontier and non-frontier firms and changes in productivity dispersion in the non-farm market sector in Canada from 1991 to 2015. Both labour productivity and MFP are examined. Labour productivity is defined as gross output per worker. MFP is defined as the ratio of gross output to combined capital, labour and intermediate inputs, using the growth accounting method.

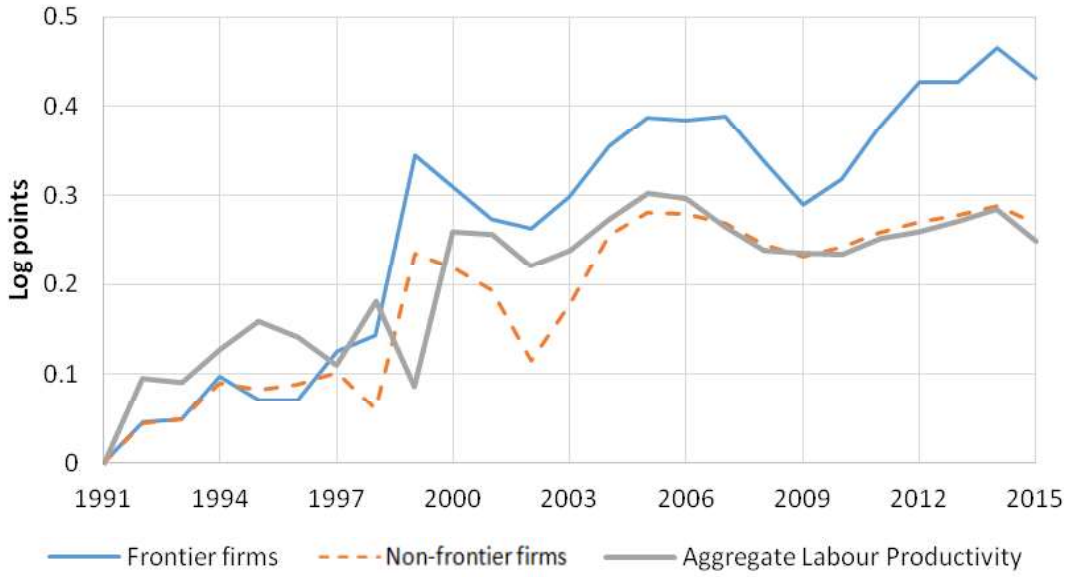
Labour productivity (gross output per worker) is presented for the 1991-2015 period. MFP (gross output per unit of combined capital, labour and intermediate inputs) is presented for the period after 2000 since the estimates of capital stock and intermediate inputs are available only after 2000.

The productivity of frontier and non-frontier firms in logarithm is estimated as each group's median productivity values. The log difference in productivity between frontier and non-frontier firms is used to measure productivity dispersion. The log difference in productivity between frontier and non-frontier firms at the three-digit NAICS level is aggregated to the log productivity difference at the two-digit NAICS level and for the non-farm market sector, using a simple mean. Therefore, the log difference in productivity at the two-digit NAICS level, or for the non-farm market sector, represents the productivity dispersion in an average three-digit NAICS industry.

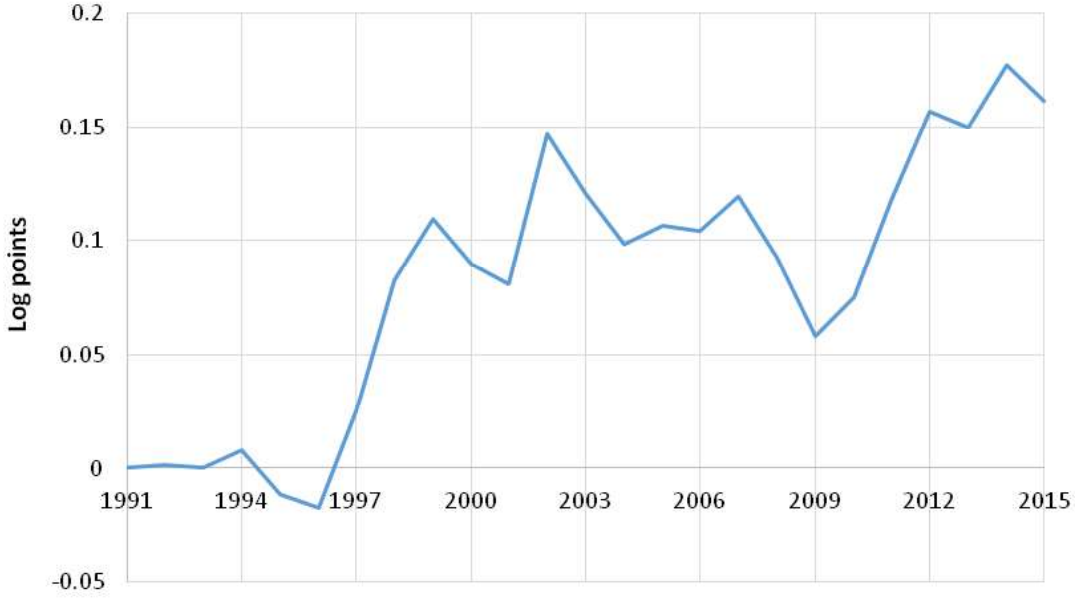
Panel A of Chart 1 presents the labour productivity of frontier and non-frontier firms, and aggregate labour productivity in the non-farm market sector for the 1991-2015 period. Panel B of Chart 1 presents the log difference in labour productivity levels between frontier and non-frontier firms over that period. The values are set to zero in 1991 in both charts. The values of the log productivity of frontier and non-frontier firms in a year represent the cumulative log growth in productivity of those two types of firms since 1991.

Chart 1: Labour Productivity, Frontier and Non-Frontier Firms in Canada, 1991-2015

Panel A: Labour Productivity of Frontier and Non-frontier Firms, 1991–2015, in logarithm, 1991 = 0



Panel B: Relative Labour Productivity of Frontier and Non-frontier Firms, 1991–2015, in logarithm, 1991 = 0



Note: Labour productivity is defined as real gross output per unit of labour.
Source: Statistics Canada, author's calculation from T2-LEAP file.

Table 1: Labour Productivity Growth in Canada (average annual rate of change)

	1991-2000	2000-2015	Change between periods (points)
Non-farm aggregate	2.90	-0.07	-2.97
Frontier firms	3.43	0.82	-2.62
Non-frontier firms	2.44	0.33	-2.10
CPA business sector	2.96	0.74	-2.22

Note: Productivity for frontier and non-frontier firms is defined as the median productivity for each group, not average productivity.
Source: T2-LEAP database for the first three roles, Canadian Productivity Accounts database for the fourth row.

Over the 1991-2015 period, the labour productivity of frontier firms increased faster than that of non-frontier firms in average Canadian industries. The labour productivity of frontier firms increased by a cumulative 0.43 log points, or 54 per cent, over the period from 1991 to 2015.[7] The labour productivity of non-frontier firms increased by 0.27 log points, or 31 per cent, in the same period.[8]

The increase in the relative productivity of frontier firms compared with that of non-frontier firms occurred in the second half of the 1990s and in the period after 2009, as shown in Panel B of Chart 1. The productivity dispersion did not change much in the early 1990s and the early 2000s. The pause in the overall trend toward productivity divergence between frontier and non-frontier firms in the first half of the 1990s and the first half of the 2000s was caused by the cyclical factors that arose from slow demand growth and a decline in capacity utilization. This affected exporters and multinationals more than other firms, at least in the manufacturing sector (Baldwin, Gu and Yan, 2013). The subsequent increase in the productivity growth gap between frontier and non-frontier firms in the second half of the 1990s and after 2009 was partially caused by increases in capacity utilization in the manufacturing industry, and likely also in other industries (Gu, 2018).

To remove the effects of those cyclical factors and focus on the effects of structural factors—such as innovation and innovation diffusion—on productivity growth, this article focuses on productivity growth for two relatively long periods: 1991–2000 and 2000–2015. The year 2000 corresponds to the turning point when productivity growth in Canada began to decline.

Annual average labour productivity growth of frontier and non-frontier firms for 1991 to 2000 and 2000 to 2015 can be calculated using the data in Panel A of Chart 1, as shown in Table 1. Labour productivity growth of frontier firms was higher than that of non-frontier firms in both periods. Labour productivity growth of both frontier and non-frontier firms declined after 2000. The decline was similar for

7 The change in log points can be converted to a percentage change by taking its natural exponent.

8 A productivity growth divergence in frontier and non-frontier firms was also found in Canadian manufacturing plants for the period from 1973 to 2015 (Gu, Yan and Ratté, 2018).

both groups. Labour productivity growth for both groups experienced approximately more than a 2-percentage-point decline between 1991–2000 and 2000–2015. Labour productivity growth of frontier firms declined from 3.43 per cent per year in 1991–2000 to 0.82 per cent per year in 2000–2015. Labour productivity growth of non-frontier firms declined from 2.44 per cent per year to 0.33 per cent per year between the two periods.

Before 2000, productivity growth in Canada was rapid. The rapid progress in ICT and the adoption of ICT and associated changes in workplace organization were the main force behind this rapid productivity growth (Gu and Willox, 2018; Ho, Rao and Tang, 2004). The implementation of the Canada–U.S. Free Trade Agreement and the North American Free Trade Agreement also contributed to productivity growth (Trefler, 2004, Baldwin and Gu, 2004). As a result, productivity growth of frontier and non-frontier firms was strong for the period from 1991 to 2000.

Productivity growth declined after 2000 for frontier and non-frontier firms. To the extent that productivity growth of frontier firms captures innovation and productivity, growth of non-frontier firms captures innovation diffusion. Evidence suggests that the pace of innovation and the pace of innovation diffusion from frontier to non-frontier firms both declined in Canada after 2000.

Chart 2 shows the capital/labour ratio, intermediate input/labour ratio, and MFP of frontier and non-frontier firms from 2000 to 2015.

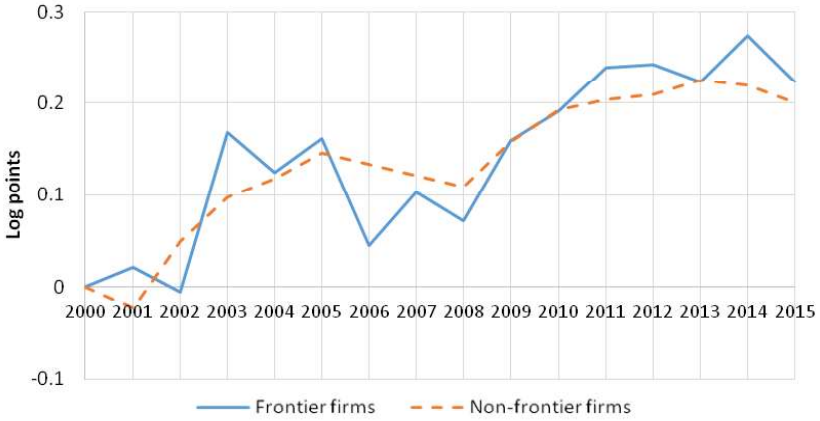
Panel A of Chart 2 shows that the capital/labour ratio increased by a similar amount for both frontier and non-frontier firms. Panel B shows that the intermediate input/labour ratio experienced little change for both frontier and non-frontier firms. Because of similar changes in capital and intermediate input intensities in frontier and non-frontier firms, most of the divergence in labour productivity between frontier and non-frontier firms for the 2000-2015 period was because of divergence in MFP growth, as shown in Panel C.

Table 2 presents labour productivity growth of frontier and non-frontier firms at the two-digit NAICS level for the 1991–2015 period, and for the 1991–2000 and 2000–2015 sub-periods. For 1991 to 2015, labour productivity growth of frontier firms was higher than that of non-frontier firms in all industries except in arts, entertainment and recreation, accommodation and food services, and other services. The biggest productivity growth difference between frontier and non-frontier firms was in utilities, mining and oil and gas extraction, broadcasting and telecommunications, finance, insurance and real estate, and wholesale and retail trade.

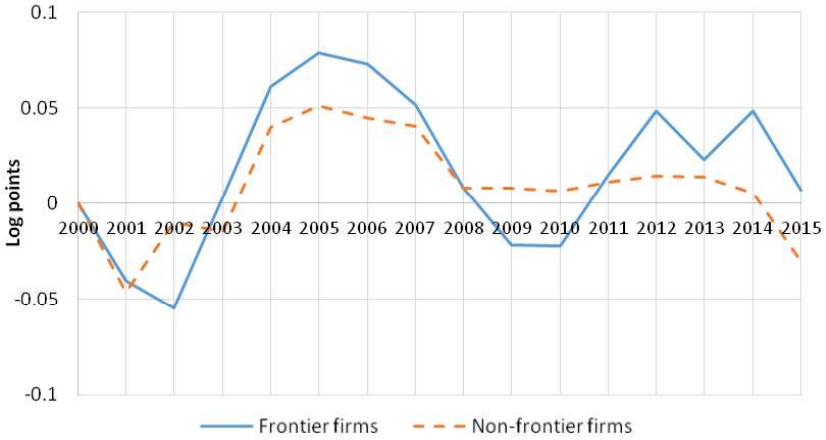
This labour productivity divergence occurred in both sub-periods (1991-2000 and 2000-2015), as shown in Panels B and C of Table 2. The productivity growth gap between frontier and non-frontier firms in the two periods was not correlated across industries. This suggests that different forces shaped the productivity divergence in those two periods. For example, the productivity divergence in the late 1990s could have been caused by the adoption of ICT and trade liberalization, while the productivity divergence in the late 2000s could have

Chart 2: Capital/Labour Ratio, Intermediate Input/Labour Ratio and Multifactor Productivity in Frontier and Non-frontier Firms in Canada, 2000-2015

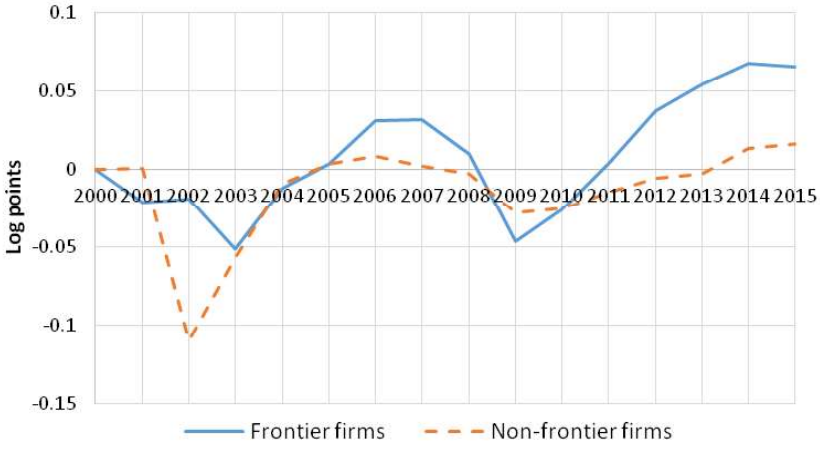
Panel A: Capital/labour Ratio of Frontier and Non-frontier Firms, 2000–2015, in logarithm, 2000 = 0



Panel B: Intermediate Input/Labour Ratio of Frontier and Non-frontier Firms, 2000–2015, in logarithm, 2000 = 0



Panel C: Multifactor Productivity of Frontier and Non-frontier Firms, 2000–2015, in logarithm, 2000 = 0



Source: Statistics Canada, author's calculation from T2-LEAP file.

Table 2: Average Labour Productivity Growth of Frontier and Non-frontier Firms by Industry, 1991–2015 (per cent per year)

Industry	Frontier Firms	Non-frontier Firms	Frontier Firms less Non-Frontier Firms
		Panel A: 1991 to 2015	
Mining and oil and gas extraction	2.16	-0.28	2.44
Utilities	7.76	4.17	3.59
Construction	1.68	0.43	1.25
Manufacturing	1.41	1.40	0.01
Wholesale and retail trrade	2.40	1.46	0.94
Transportation and warehousing	1.79	1.25	0.54
Information and culture	1.74	1.01	0.73
Broadcasting and telecommunications	2.05	0.49	1.55
Finance, insurance and real estate	1.48	0.34	1.14
Arts, entertainment and recreation	0.56	0.76	-0.20
Accommodation and food services	0.29	0.53	-0.24
Other services	0.65	0.98	-0.33
All industries	1.80	1.12	0.67
		Panel B: 1991 to 2000	
Mining and oil and gas extraction	5.24	2.25	3.00
Utilities	17.69	6.45	11.24
Construction	4.03	2.69	1.34
Manufacturing	2.41	1.91	0.50
Wholesale and retail trade	4.54	3.27	1.28
Transportation and warehousing	3.75	3.39	0.36
Information and culture	1.61	1.61	0.01
Broadcasting and telecommunications	4.57	1.35	3.23
Finance, insurance and real estate	1.46	1.41	0.05
Arts, entertainment and recreation	1.16	2.47	-1.31
Accommodation and food services	2.10	1.31	0.79
Other services	1.80	1.88	-0.08
All industries	3.43	2.44	1.00
		Panel C: 2000 to 2015	
Mining and oil and gas extraction	0.83	-1.57	2.40
Utilities	3.31	2.58	0.72
Construction	0.85	-0.70	1.55
Manufacturing	0.73	0.81	-0.08
Wholesale and retail trade	1.17	0.40	0.77
Transportation and warehousing	0.65	-0.02	0.67
Information and culture	0.89	0.68	0.20
Broadcasting and telecommunications	2.99	2.23	0.76
Finance, insurance and real estate	1.98	0.12	1.86
Arts, entertainment and recreation	0.30	-0.66	0.96
Accommodation and food services	-0.36	0.24	-0.60
Other services	0.70	0.54	0.16
All industries	1.05	0.51	0.54

Note: Frontier firms are defined as the top 10 per cent most productive firms in a three- digit NAICS industry and in a year.
Source: Statistics Canada, author's calculation from T2-LEAP file.

been caused by the use of digital technologies and the increased competition from emerging economies.

Contribution of frontier and non-frontier firms to aggregate productivity growth

This sub-section decomposes aggregate productivity growth into contributions of frontier and non-frontier firms. The aggregate labour productivity growth in an industry can be decomposed into three components: contribution from frontier firms, contribution from non-frontier firms, and contribution from share changes of frontier and non-frontier firms.

Specifically, aggregate labour productivity in year t (p^t) is equal to a weighted average of labour productivity of frontier and non-frontier firms:

$$p^t = s_1^t p_1^t + s_0^t p_0^1, \quad (1)$$

where s_1^t is the share of frontier firms in employment in year t, s_0^t is the share of non-frontier firms in total employment in year t, p_1^t is the labour productivity of frontier firms in year t, and p_0^t is the labour productivity of non-frontier firms in year t.

The change in aggregate labour productivity between year $t-1$ and year t can be written as:

$$p^t - p^{t-1} = \bar{s}_1(p_1^t - p_1^{t-1}) + \bar{s}_0(p_0^t - p_0^{t-1}) + (\sum_{i=0,1} s_i^t - s_i^{t-1})\bar{p}_i, \quad (2)$$

where a bar over a variable presents the average values of the variable in years $t-1$ and t. The first term on the right is the contribution of frontier firms to aggregate labour productivity growth, which is estimated as the change in labour productivity of the frontier firms between two years, multiplied by the shares of frontier firms in total employment averaged over two years. The second term is the contribution of non-frontier firms to aggregate labour productivity growth, which is equal to the change in labour productivity of the non-frontier firms multiplied by the share of non-frontier firms in total employment. The third term is the contribution of the employment share changes of frontier and non-frontier firms. This contribution is positive when there is a shift in the shares of employment toward frontier firms, which are more productive.

The decomposition is expressed in labour productivity levels. To implement the decomposition, labour productivity will be expressed in logarithms to reduce the impact of extreme values on the estimates, a practice that is commonly used in labour productivity decomposition (e.g. Foster, Haltiwanger and Krizan, 2001; Baldwin and Gu, 2006; OECD, 2017).

To ensure that the sum of the three components in the decomposition is equal to aggregate labour productivity growth, the labour productivity of frontier and non-frontier firms is calculated as a weighted average of labour productivity in that group of firms, using employment as weights. This differs from the earlier analysis of productivity dispersion of frontier and non-frontier firms, where the productivity of a group of firms was estimated as the median value of that group.

Table 3: Average Share of Frontier Firms in Total Employment and Gross Output in Per Cent, 1991–2015

	Share of Employment	Share of Output
Mining and oil and gas extraction	16.54	43.67
Utilities	8.95	47.56
Construction	4.33	20.18
Manufacturing	17.21	48.11
Wholesale and retail trade	7.27	29.16
Transportation and warehousing	5.31	31.46
Information and culture	6.46	25.29
Broadcasting and telecommunications	12.70	36.86
Finance, insurance and real estate	3.81	27.22
Arts, entertainment and recreation	5.27	37.11
Accommodation and food services	2.23	7.68
Other services	4.59	21.23
All industries	7.89	31.29

Note: Frontier firms are defined as the top 10 per cent most productive firms in a three- digit NAICS industry and in a year.
Source: Statistics Canada, author's calculation from T2-LEAP file.

The decomposition of aggregate labour productivity into the contributions of frontier and non-frontier firms is done at the three-digit NAICS level. The results are then aggregated to the two-digit NAICS level and to the non-farm market sector, using industry employment as weights.

Table 3 presents average shares of frontier and non-frontier firms in employment, and average output by industry. Frontier firms accounted for 8 per cent of total employment and about 30 per cent of gross output in Canadian industries in 1991-2015.

The share of total employment accounted for by frontier firms declined from 10 per cent in 1991 to 6 per cent in 2015. The fact that the share of frontier firms in total employment was the same as their share in the number of the most productive firms (at 10 per cent) in 1991 suggests that frontier firms were similar in size to non-frontier firms in terms of employment. However, by 2015, the share of frontier firms in total employment was smaller than their share in the number of firms. This suggests that average employment size in frontier firms was smaller than non-frontier firms in 2015.

The share of total employment accounted for by frontier firms differed across industries, as shown in Table 3. The frontier firms were smaller than the non-frontier firms in terms of employment in most industries, except mining and oil and gas extraction, manufacturing, and broadcasting and telecommunications.

The share of gross output accounted for by frontier firms averaged about 30 per cent in the 1991-2015 period, and was virtually unchanged over that period. When size is measured by gross output, frontier firms were larger than non-frontier firms in all industries except accommodation and food services. In this industry, frontier firms were smaller than non-frontier firms in terms of gross output.

Table 4 presents a decomposition of aggregate labour productivity growth in the non-farm market sector into the contributions of frontier and non-frontier firms. Frontier firms accounted for 11 per cent

Table 4: Contributions of Frontier and Non-frontier Firms to Aggregate Labour Productivity Growth (per cent per year), 1991–2000 and 2000–2015

	1991-2000	2000-2015	2000-2015 less 1991 to 2000
Non-farm Market Labour Productivity Growth	3.55	0.34	-3.21
Contributions of			
Frontier Firms	0.39	0.03	-0.36
Non-frontier Firms	3.30	0.35	-2.95
Share Changes	-0.14	-0.04	0.10
Addendum			
Labour Productivity Growth of			
Frontier Firms	3.43	1.51	-1.92
Non-frontier Firms	2.44	0.51	-1.93
Share of Frontier Firms in Employment (per cent)	8.74	7.06	

Note: Frontier firms are defined as the top 10 per cent most productive firms in a three- digit NAICS industry and in a year. The labour productivity of frontier and non-frontier firms is estimated as a weighted average of each group's productivity values.
Source: Statistics Canada, author's calculation from T2-LEAP file.

of aggregate labour productivity growth in the 1991-2000 period (0.39/3.55), and 9 per cent of aggregate labour productivity growth in the 2000-2015 period. The contributions of frontier firms to aggregate labour productivity were higher than their shares in employment because of the relatively high productivity growth of the frontier firms compared with that of non-frontier firms.

The contributions of frontier and non-frontier firms to aggregate labour productivity growth declined after 2000. This suggests that the contributions of innovation and innovation diffusion to aggregate labour productivity growth both declined. The decline in innovation in frontier firms and the decline in innovation diffusion from frontier firms to non-frontier firms both contributed to the productivity slowdown after 2000 in Canada.

Most of the decline in labour productivity growth is from the decline in the contribution of non-frontier firms. The decline in innovation diffusion had more of an impact on the post-2000 productivity slowdown in Canada than the decline in innovation. The decline in labour productivity growth of non-frontier firms after 2000 accounted for 2.95 percentage points, or 90 per cent, of a 3.21 percentage-point decline in aggregate labour productivity growth in that period. The decline in labour productivity growth of frontier firms contributed about 10 per cent of aggregate labour productivity growth after 2000.

Table 5 presents the decomposition of aggregate labour productivity growth into the contributions of frontier and non-frontier firms at the two-digit NAICS industry level for the 1991–2000 and 2000–2015 periods, and the contributions of frontier and non-frontier firms to the decline in labour productivity growth between the two periods.

Labour productivity growth declined after 2000 in all industries except utilities. Both frontier and non-frontier firms contributed to this decline in labour productivity since the productivity growth of both groups of firms declined after 2000 in all industries, except for non-frontier firms in

Table 5: Contributions of Frontier and Non-frontier Firms to Labour Productivity Growth by Industry (per cent per year), 1991–2000 and 2000–2015

	Labour Productivity Growth	Contributions from: Frontier Firms	Non-frontier Firms	Share Changes
		1991–2000		
Mining and oil and gas extraction	3.74	0.95	3.41	-0.62
Utilities	-9.62	1.79	-5.84	-5.57
Construction	2.24	0.18	2.16	-0.10
Manufacturing	4.15	0.38	3.10	0.67
Wholesale and retail trade	5.03	0.55	4.98	-0.49
Transportation and warehousing	4.14	0.44	3.42	0.28
Information and culture	5.74	0.40	5.58	-0.25
Broadcasting and telecommunications	2.35	0.53	2.75	-0.92
Finance, insurance and real estate	2.09	0.07	1.99	0.02
Arts, entertainment and recreation	1.61	0.41	0.94	0.26
Accommodation and food services	1.85	0.08	1.84	-0.08
Other services	4.07	0.18	4.05	-0.16
All industries	3.55	0.39	3.30	-0.14
		2000–2015		
Mining and oil and gas extraction	-3.63	0.29	-3.00	-0.92
Utilities	12.21	-0.04	12.73	-0.48
Construction	-0.43	-0.03	-0.32	-0.08
Manufacturing	1.82	0.32	1.53	-0.04
Wholesale and retail trade	-0.19	-0.17	-0.36	0.33
Transportation and warehousing	0.30	-0.19	0.42	0.07
Information and culture	-0.26	0.16	-0.46	0.05
Broadcasting and telecommunications	0.21	0.13	0.72	-0.64
Finance, insurance and real estate	0.02	0.05	0.08	-0.11
Arts, entertainment and recreation	0.25	-0.02	0.32	-0.05
Accommodation and food services	-0.18	-0.02	-0.15	0.00
Other services	0.70	0.10	0.95	-0.36
All industries	0.34	0.03	0.35	-0.04
	Labour Productivity Growth, 2000–2015 less 1991–2000	Contributions from: Frontier Firms	Non-frontier Firms	Share Changes
Mining and oil and gas extraction	-7.37	-0.66	-6.41	-0.30
Utilities	21.83	-1.84	18.58	5.08
Construction	-2.67	-0.21	-2.48	0.02
Manufacturing	-2.33	-0.06	-1.57	-0.70
Wholesale and retail trade	-5.23	-0.72	-5.34	0.83
Transportation and warehousing	-3.84	-0.63	-3.00	-0.20
Information and culture	-5.99	-0.25	-6.04	0.30
Broadcasting and telecommunications	-2.14	-0.39	-2.03	0.28
Finance, insurance and real estate	-2.07	-0.02	-1.92	-0.13
Arts, entertainment and recreation	-1.36	-0.43	-0.62	-0.31
Accommodation and food services	-2.03	-0.11	-1.99	0.07
Other services	-3.38	-0.08	-3.10	-0.20
All industries	-3.21	-0.36	-2.95	0.10

Note: Frontier firms are defined as the top 10 per cent of the most productive firms in a three- digit NAICS industry and in a year.
Source: Statistics Canada, author's calculation from T2-LEAP file.

utilities. This suggests that innovation and innovation diffusion both declined, contributing to the decline in productivity growth after 2000 in almost all industries in Canada.

Although the relative importance of innovation and innovation diffusion for productivity growth is sensitive to the definition of frontier and non-frontier firms, the overall conclusion that declines in innovation and in innovation diffusion contributed to the post-2000 decline in productivity growth is not. The same results hold when frontier firms are defined as the top 5 per cent, top 15 per cent or top 20 per cent of firms in terms of productivity levels.

To further assess the robustness of the results, an alternative approach — stochastic frontier analysis — will be used in the next section to examine the contribution to aggregate labour productivity growth of innovation in frontier firms and the catch-up of non-frontier firms to frontier firms.

Technical Progress of Frontier Firms and Catch-up of Non-Frontier Firms

This section uses the stochastic frontier approach of Meeusen and van den Broeck (1977) and Aigner, Lovell and Schmidt (1977) to decompose aggregate productivity growth into technical change and technical efficiency change. In this approach, technical change can be defined as the innovation and productivity growth of the most efficient firms, and technical efficiency change can be defined as the catch-up of non-frontier firms to frontier firms, or technical diffusion from frontier to non-frontier firms.[9] The stochastic frontier approach provides an alternative decomposition of productivity growth into the contributions of innovation in frontier firms and innovation diffusion from frontier to non-frontier firms.

The stochastic frontier production function establishes a statistical relationship between inputs and outputs for the most efficient, or frontier, firms. A shift in the frontier production function represents the productivity growth of the frontier firms. The residuals in the stochastic frontier production function measure the productivity of non-frontier firms, relative to the frontier firms.

Specifically, the stochastic frontier production function can be written as:

$$y_{it} = \alpha_o + \alpha_1 x_{it} + \sum_{t=1991}^{2015} \alpha_t dyear_t + \sum_{n=1}^{N} \beta_n dind_n + \sum_{t=1991}^{2015} \sum_{n=1}^{N} \gamma_{t,n} dyear_t * dind_n + \varepsilon_{it} \quad (3)$$

$$\varepsilon_{it} = v_{it} - u_{it}$$

$$v_{it} \sim N(0, \sigma_v^2)$$

$$u_{it} \sim N^+(0, \sigma_u^2)$$

9 Rada and Valdes (2012) adopted this approach to decompose the productivity growth of Brazilian agriculture into contributions from technical change and technical efficiency change.

where y_{it} represents the logarithm of gross output of firm i in year t; x_{it} is a vector of inputs in logarithm; $dyear_t$ is a full set of year dummies; $dind_n$ is a full set of industry dummies; and α, β, γ are the parameters to be estimated. The composite error term ε_{it} is a sum of two components: a normally distributed error term v_{it} that represents measurement and specification errors, and a one-sided normally distributed disturbance u_{it} that represents inefficiency.

In previous studies on productivity dispersion and productivity growth dynamics, the residual $\hat{\varepsilon}_{it}$ is interpreted as the productivity of non-frontier firms relative to frontier firms (Bartelsman and Wolf, 2017; Foster *et al.*, 2016). This differs from the interpretation in the stochastic frontier analysis. In the stochastic frontier analysis, the residual $\hat{\varepsilon}_{it}$ consists of two components: $\hat{\varepsilon}_{it} = \hat{v}_{it} - \hat{u}_{it}$. Only one component, $\hat{u}_{it}$, measures the productivity of a firm relative to that of a frontier firm. The other component, $\hat{v}_{it}$, represents measurement or specification errors. This article will adopt the interpretation from studies on productivity dispersion and productivity growth dynamics. The composite residual $\hat{\varepsilon}_{it}$ is used to measure the productivity of a firm relative to frontier firms.

The frontier production function is estimated using a cross-sectional stochastic model. The dependent variable is labour productivity (gross output per worker) in logarithm. The independent variables include labour in logarithm, a full set of years, a full set of industry dummies for two-digit NAICS industries, and interaction of year and industry dummies.[10]

The estimated stochastic frontier model can be used to decompose aggregate labour productivity into two components: technical progress that represents the shifts in the frontier production function, and technical efficiency change that represents the catch-up of average firms to the production frontiers. The coefficient estimates on the full set of year dummies and industry dummies, and the interaction of year and industry dummies, provide an estimate of shifts in the frontier production function or technical progress of the most productive firms in each year. Technical progress is allowed to differ across industries in the specification. The estimated residuals are aggregated to an industry, using employment as weights, to derive a measure of technical efficiency change. The sum of technical change and technical efficiency change is equal to aggregate labour productivity growth.

The results are presented in Table 6. Labour productivity growth declined in the non-farm market sector after 2000. The decline was caused by a decline in technical change and technical efficiency change. This can be seen as evidence that the pace of innovation in frontier firms and the rate of innovation diffusion from frontier firms to non-frontier firms both declined after 2000, contributing to the decline in aggregate labour productivity growth.

The stochastic frontier analysis and the productivity decomposition into contribu-

10 When industry dummies are defined at the three-digit NAICS level, estimating the stochastic frontier model takes longer, but the results are similar. To provide a decomposition of MFP, the independent variables would include capital, labour and intermediate inputs in logarithms.

Table 6: Technical Changes, Technical Efficiency Changes and Labour Productivity Growth in the Non-Farm Market Sector (per cent per year), 1991–2000 and 2000–2015

	1991-2000	2000-2015	2000 to 2015 less 1991 to 2000
Aggregate labour productivity growth	3.55	0.34	-3.21
Contributions of			
Frontier technical changes	2.44	0.11	-2.33
Non-Frontier technical efficiency changes	1.09	0.26	-0.83
Residual	0.02	-0.03	-0.05

Source: Statistics Canada, author's calculation from the T2-LEAP file.

tions of frontier and non-frontier firms both show that innovation and diffusion of innovation declined in Canada after 2000. However, the two methods differ on the relative contribution of innovation and innovation diffusion to the productivity slowdown. The results from a productivity decomposition into contributions of frontier firms show that the slowdown in the diffusion of innovation is a main source of the productivity slowdown after 2000. That is because the decline in labour productivity growth of non-frontier firms after 2000 is found to account for 2.95 percentage points, or 90 per cent, of a 3.21 percentage-point decline in aggregate labour productivity growth between the periods of 1991 to 2000 and 2000 to 2015. In contrast, the results from a stochastic frontier analysis show that the decline in innovation is the main source of the productivity slowdown after 2000. That is the case as a decline in technical change and innovation by frontier firms accounted for 2.33 percentage points, or 73 per cent, of a 3.21 percentage-point decline in aggregate labour productivity growth, and a decline in catch-up of non-frontier firms to frontier firms accounted for the remainder of the slowdown.

While data on tangible assets are available only after 2000, data on total assets are available for the entire 1991–2015 period. Total assets were found to be highly correlated with tangible assets across firms, and were used as measures of capital stock when estimating the stochastic frontier production function on gross output, which includes labour and capital as inputs for the period of 1991 to 2015. The productivity estimate from this expanded stochastic frontier model provides a measure of a partial MFP that includes capital and labour as inputs, but excludes intermediate inputs. The results from this expanded stochastic frontier model are similar to the results that include only labour as an input. Both technical change and technical efficiency change measured on partial MFP declined after 2000. This decline contributed to a decline in MFP growth after 2000.

Resource Reallocation and Aggregate Labour Productivity Growth

Aggregate productivity growth can increase when productivity increases within firms, or when the share of employment and output increases in more productive firms and falls in less productive firms. Decker *et al.* (2016) found that this reallocation

happened to a lesser extent in the post-2000 period, particularly in the high-tech sector, with implications for overall productivity growth.

This section uses the Olley and Pakes (OP) decomposition to decompose aggregate labour productivity growth into the contribution from productivity growth within firms and the contribution from the reallocation of employment between firms (Olley and Pakes, 1996).

Aggregate labour productivity in an industry is equal to the sum of an unweighted average of firm-level productivities and a covariance term that represents reallocation (also called the OP gap). The latter is a measure of allocative efficiency, since it increases if more productive firms increase their share of resources in the sector:

$$p^t = \frac{1}{N}\sum_{i=1}^{N} p_{it} + \sum_{i=1}^{N}(s_{it} - \bar{s}_t)\,(p_{it} - \bar{p}_t)\,, \tag{4}$$

$$p^t = \sum_{i=1}^{N} s_{it} p_{it}, \tag{5}$$

where p_t is the aggregate labour productivity level in year t, which is equal to a weighted sum of labour productivity across firms using employment as weights; p_{it} is the labour productivity level of firm i in year t; and s_{it} is the share of firm i in total employment in year t. A bar over a period is the simple unweighted mean of that variable in that industry. While labour productivity is measured in levels in this OP decomposition, it will be measured in log terms in its implementation to alleviate the effect of extreme values.

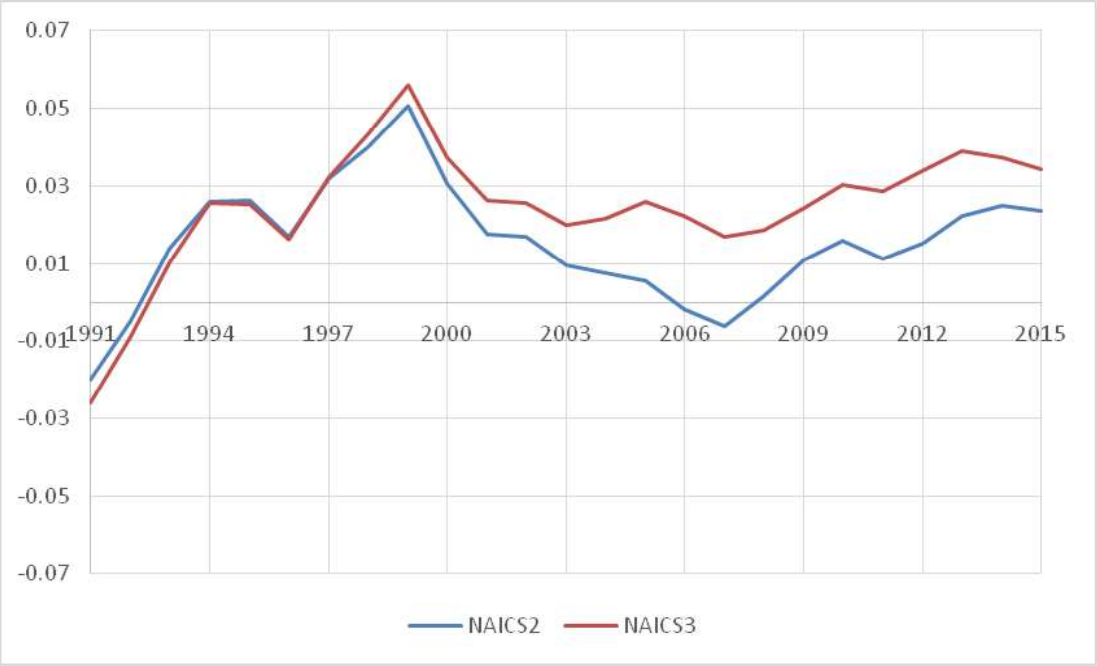
When labour productivity is measured in log terms, the log changes in aggregate labour productivity are the sum of log changes in unweighted labour productivity and the log changes in the OP covariance term. The log changes in the unweighted mean of labour productivity over a period measure the contribution of productivity growth within firms to aggregate labour productivity growth. The log changes in the OP gap measure the contribution of reallocation to aggregate labour productivity growth.

Chart 3 presents the trend in the OP covariance term. As labour productivity is measured in logs, the changes in OP covariance measure the gains in labour productivity from reallocation. The chart presents two measures of the OP covariance term. The first measure is calculated at the two-digit NAICS level and then aggregated to the total non-farm market sector using employment as weights. The second measure is calculated at the three-digit NAICS level and then aggregated to the total non-farm market sector. Both measures show similar trends.

There was an increase in the index of reallocation in the 1990s as labour was reallocated to firms with relatively higher labour productivity levels. The reallocation occurred as employment shifted from growing incumbents and entrants with relatively higher productivity levels to declining incumbents and exitors with relatively lower productivity levels. The effect of reallocation declined in the early 2000s as a result of slow growth and the tech bubble bursting in that period. After the financial crisis, there was an increase in the effect of reallocation on labour productivity growth.

The recession in the early 1990s in

Chart 3: Index of Between-Firm Reallocation in Canadian Industries, 1991–2015



Note: The index of between-firm reallocation is calculated as a 3-year moving average of the Olley-Pakes covariance term.
Source: Statistics Canada, author's calculation from T2-LEAP file.

Canada is associated with an increase in the effect of reallocation on productivity growth, possibly because the recession drove out the least efficient firms. The slow growth of the early 2000s is associated with a decline in the effect of reallocation, possibly because of distortions to reallocation dynamics. This evidence for Canada is broadly consistent with the evidence of Foster, Grim and Haltiwanger (2016) for the United States.

Overall, the improved reallocation at the three-digit NAICS level contributed 0.70 per cent per year to aggregate labour productivity growth for the 1991–2000 period (Table 7). The improved reallocation at the two-digit NAICS level contributed 0.6 per cent per year to aggregate labour productivity growth. The effect of reallocation on aggregate productivity growth was essentially zero over the period of 2000 to 2015. An increasing reallocation effect in the late 2000s was more than offset by the declining reallocation effect before the 2008–2009 financial crisis.

This suggests that the decline in aggregate labour productivity growth after 2000 was partly due to a decline in the contribution of resource reallocation in that period. The decline in the effect of resource reallocation is consistent with the evidence on the decline in business start-ups and business dynamism in Canada over time, which contributed to the decline in aggregate labour productivity growth after 2000.

Table 7: Contributions of Reallocation and Within-firm Growth to Aggregate Labour Productivity Growth (per cent per year), 1991 to 2000 and 2000 to 2015

	1991 to 2000	2000 to 2015	2000 to 2015 less 1991 to 2000
Aggregate labour productivity growth	3.55	0.34	-3.21
Contributions of			
Reallocation	0.70	-0.02	-0.72
Within-firm productivity growth	2.85	0.36	-2.49

Note: The effect of reallocation is calculated as the changes in the Olley-Pakes co-variance term at the three digit level of North American Industry Classification System.
Source: Statistics Canada, author's calculation from the T2-LEAP file.

Conclusion

Productivity growth has slowed in Canada since the 2000s. This article examined the causes of the productivity slowdown in Canada. It found that labour productivity growth of frontier firms was higher than that of non-frontier firms. However, labour productivity growth declined for both frontier and non-frontier firms after 2000. This suggests that the pace of innovation and the pace of innovation diffusion from frontier to non-frontier firms both declined in Canada after 2000.

A stochastic frontier analysis that decomposed labour productivity growth into contributions from technical change and technical efficiency change confirmed the decomposition results from the classification of firms into frontier and non-frontier firms: the decline in aggregate labour productivity was caused by the post-2000 declines in technical change and technical efficiency change. This can be interpreted as evidence that the pace of innovation in frontier firms and the rate of innovation diffusion from frontier firms to non-frontier firms both declined after 2000, contributing to aggregate labour productivity slowdown after 2000.

While both innovation and diffusion of innovation declined in Canada after 2000, the relative contribution of innovation and diffusion of innovation to the productivity slowdown is sensitive to the methods adopted. The results from a productivity decomposition into contributions of frontier firms and non-frontier firms show that the slowdown in the diffusion of innovation is a main source of the productivity slowdown after 2000, as the decline in labour productivity growth of non-frontier firms after 2000 accounted for 2.95 percentage points, or 90 per cent, of a 3.21-percentage-point decline in aggregate labour productivity growth between the periods of 1991 to 2000 and 2000 to 2015.

In contrast, the results from a stochastic frontier analysis show that the decline in innovation is the main source of the productivity slowdown after 2000. That is the case because a decline in technical change and innovation by frontier firms from the stochastic frontier analysis accounted for 2.33-percentage points, or 73 per cent, of a 3.21-percentage-point decline in aggregate labour productivity growth, and a decline in catch-up of non-frontier firms to frontier firms accounted for the remainder of the slowdown

Improved resource reallocation contributed significantly to aggregate labour productivity growth in the 1991–2000 period, but the effect of reallocation was essentially zero over the period from 2000 to 2015. The decline in aggregate labour productivity growth after 2000 was thus partly caused by the decline in the contribution of resource reallocation, which is consistent with previous evidence on declining business start-ups in Canada. Business start-ups and business dynamism appear to decline in Canada over time, and this contributed to the decline in aggregate labour productivity growth after 2000.

In summary, the decline in aggregate labour productivity growth in Canada after 2000 was found to be caused by a decline in innovation in frontier firms, a decline in innovation diffusion from frontier firms to non-frontier firms, and a decline in the effect of resource reallocation and business dynamism on productivity growth.

While innovation in frontier firms declined after 2000, the exact causes of this decline are not known. This could support the findings of Gordon (2016), which state that current technological advances such as mobile technology, the internet and cloud computing are not great enough to drive strong productivity growth. Or, the new digital economy has yet to generate gains in productivity (van Ark, 2016). Lastly, frontier firms were defined as the most productive firms in Canada. It is possible that frontier firms in Canada are less productive than global frontier firms. Therefore, the slower productivity growth of frontier firms may reflect a lack of innovation diffusion from global frontier firms to firms operating in Canada.

The diffusion of innovation from frontier to non-frontier firms also declined after 2000. This occurred in a period marked by digitalization, the increasing complexity of technologies, and the rising importance of tacit knowledge. That digitalization has enabled the development of a winner-take-all dynamic where technology leaders can capture most of the market share because they can replicate their provision of information goods and business processes at a low cost in a country and around the globe.

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