Frontier Firms, Productivity Dispersion and Aggregate Productivity Growth

Wulong Gu

(Statistics Canada)

Paper prepared for the 35th IARIW General Conference

Copenhagen, Denmark, August 20-25, 2018

Session 6C-1: Is Productivity Growth Slowing Down? II

FRIDAY, AUGUST 24 11:00-12:30

Frontier Firms, Productivity Dispersion and Aggregate Productivity Growth

Wulong Gu

Economic Analysis Division

Statistics Canada

August 2018

This paper is prepared for IARIW conference in Copenhagen, Demark. I would like to thank D. Greakou, H. Liu, Danny Leung and W. Wang for helpful discussions.

Contact: Wulong Gu, Economic Analysis Division, Statistics Canada. email, wulong.gu@canada.ca

Abstract

This paper examines the causes of the productivity slowdown after 2000 in Canada. A comparison of frontier and non-frontier firms shows that the decline in aggregate labour productivity after 2000 was due to a decline in the contribution of frontier and non-frontier firms, but mainly from that of non-frontier firms. A stochastic frontier analysis shows the decline in aggregate labour productivity was due to a decline in technical change of most efficient firms and a decline in technical efficiency change of average firms after 2000. This can be interpreted as the evidence that the pace of innovation at frontier firms and the rate of diffusion from frontier firms to non-frontier firms both declined after 2000, contributing to aggregate productivity slowdown after 2000. Consistent with OECD (2015), the evidence for Canada shows that a main cause of the productivity slowdown is a slowing of the pace of diffusion from frontier firms to non-frontier firms or a breakdown of the diffusion machine which took place after 2000. Finally, the paper finds 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, which is consistent the evidence on declining business start-ups and its implication for declining productivity growth.

1. Introduction

Productivity growth slowed in all main developed countries including Canada since 2000s. Labor productivity in the U.S. had been growing at an average pace of 2.1 percent year over year. Then in 2004, the rate of productivity growth began to decelerate, falling to an average of 1.2 percent per year during the decade to 2014 (Manyika, et al., 2017, Sharpe and Murray, 2018). Labour productivity growth in Canada started to decline in 2000, from 1.7% per year in the period 1980 to 2000 to 1.0% per year in the period 2000 to 2015 (Gu, 2018). The 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).

The previous studies have identified a number of explanations for this trend. While the slowdown in productivity growth after 2000 is partly due to the cyclical factors such as the slow output growth and the burst of dot-com bubble in the early 2000s and the global financial crisis of 2008 and 2009, a number of structural factors have been suggested as important explanations for this slowdown in productivity growth. They include a slower pace of innovation and technological progress, a slowdown in the diffusion of innovation, changes in competitive intensity, a decline in business dynamism, and the misallocation of resources possibly due to the sharp decline in real interest rates (Bailey and Montalbano, 2016; Cette et al. 2016, OECD, 2015, Sharpe and Murray, 2018).

This paper examines the causes of productivity growth slowdown in Canada after 2000. It has main two main objectives.

First, the paper will examine the role of innovation and technical progress at the frontier firms and the diffusion of innovation and technical progress from the frontier firms to the non-frontier firms for the decline in productivity growth after 2000. According to Gordon (2016), it is the slow pace of innovation that is behind the productivity slowdown in the developed countries. Gordon (2016) believe that current technological advances such as digital technologies, robots and cloud computing are not great enough to drive strong productivity growth. The historical innovations such as steam engines and electricity had a far greater impact on productivity growth than current technological change. An alternative explanation for the productivity slowdown is provided by OECD (2015). OECD presented empirical evidence that the main source of the productivity slowdown is not a slowing in the rate of innovation by the frontier firms, but rather a slowing of the pace of diffusion from frontier firms to non-frontier firms or a breakdown of the diffusion machine which took place sometime in the early 2000s (Andrews, Criscuolo and Gal, 2015, OECD 2015).

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

To assess the relative importance of innovation and diffusion for the productivity slowdown after 2000, this paper divides all firms in an industry to 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. The frontier firms are defined as the 10% most productive firms in an industry and the non-frontier firms are defined as all other firms. The changes in productivity growth of frontier firms over time are used to assess the pace of innovation over time. The changes in productivity growth of non-frontier firms are used to assess the pace of diffusion over time.

In addition to this accounting approach for assessing the role of innovation at frontier firms and the diffusion from frontier to non-frontier firms for the productivity slowdown, the paper will estimate a stochastic frontier production function that is then used to decompose productivity growth into contribution from technical change and contribution from technical efficiency change. Technical change in the stochastic frontier analysis is defined as the productivity growth of most productive firms that form the production frontier. Technical efficiency change is defined as a measure of change in productivity gap of average firms and the most productive firms over time. For the purpose of this paper, technical change is interpreted as the pace of innovation at the frontier firms and technical efficiency change represents the rate of diffusion from frontier to non-frontier firms.

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

Haldane (2017) concluded that the decline in productivity growth in the UK after the financial crisis compared with that in the early 2000s is due to the poor productivity growth performance of the non-frontier firms. Cette et al. (2017) found that the productivity growth of frontier firms in France increased after 2000, which is consistent with OECD (2017) that the pace of innovation did not decline in the 2000s. But they found no evidence that the diffusion of innovation 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 2000s and used this to provide evidence on the role of innovation and diffusion for aggregate productivity growth in the 2000s. But as Andrews, Criscuolo and Gal (2015) noted, this data limitation makes it difficult to say whether productivity growth of frontier and non-frontier firms has slowed relative to the period before 2000 and thus the evidence for the 2000s period only cannot be used to examine the role of innovation and diffusion for the productivity slowdown after 2000. This paper will examine a long-term trend in the productivity growth of frontier and non-frontier firms over 1991 to 2015, which can be used to examine the contribution of innovation at the frontier firms and the diffusion from frontier to non-frontier firms to the decline in aggregate productivity growth after 2000.

The rest of the paper is organized as follows. Section 2 presents the data used for the analysis. Section 3 presents productivity dispersion of frontier and non-frontier firms and their contribution to aggregate productivity growth. Section 4 uses the stochastic frontier analysis to decompose productivity growth into innovation at the frontier firms and the diffusion from frontier to non-frontier firms. Section 5 examines the effect of reallocation on productivity growth over time and its contribution to decline in productivity growth after 2000. Section 6 concludes.

2. Data Sources

The data used for this paper is Statistics Canada's T2-LEAP longitudinal firm-level database. This is a database that was derived from linking two administrative data bases. The first database – the Longitudinal Employment Analysis Program (LEAP) file – is a database that includes all employers in Canada, both incorporated and unincorporated, that register a payroll deduction account with Canadian Revenue Agency (CRA). This file contains a longitudinal firm identification number that can be used to examine the growth, entry and exit of firms. The firms in the LEAP file have been assigned to NAICS Standard Industrial Classification industries.

For research purposes, the LEAP file has been linked to the Corporate Tax Statistical Universal File (T2) that includes all incorporated firms that file a T2 tax return with Canadian Revenue Agency. The linked T2-LEAP file provides data on total payroll, sales, gross profits, equity, 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. The ALUs for a firm is calculated as the ratio of the total payroll of the firm to average annual wages of the workers in that firm's industry, size class and province.[1]

The database is cleaned for outliers, using a method based on the outliers principle developed by John Tukey (Tukey 1977, Cette, et al, 2017), which deletes values located beyond quartile 1 (and 3) which are less (and more) than three times the interquartile spread of labour productivity levels at NAICS 3 digit level of industry classification in a year. About 1% of the observations are classified as outliers using this method and they are removed for the analysis of the paper.

This paper will focus on the non-farm market sector that excludes the agriculture, forestry and fishing, health and education, and public administration sectors. It will examine both labour productivity and multifactor productivity (MFP) of the non-farm market sector. Labour productivity is defined as real gross output per worker. The data on labour productivity, output, and employment are available for the period 1991 to 2015. MFP is defined as gross output per unit of combined capital, labour and intermediate inputs. Capital input for measuring MFP is estimated as book values of tangible assets deflated by industry capital stock deflator. Intermediate input is measured as sales minus the sum of payroll and capital income (estimated as net income before taxes). The data on MFP and related output and input measures are available for the period 2000 to 2015 as robust values of tangible assets and intermediate inputs are only available after 2000.

As shown Figure 1, the labor productivity measure (gross output for worker) derived from the t2-leap micro data file for the nonfarm market sector shows a similar trend as the labour productivity measure for the business sector from the industry productivity database of Statistics Canada. For a comparison of labour productivity measure between the micro data file and the industry productivity database, labour productivity for the business sector from the industry productivity database is defined as gross output per hours worked, which differs from the official measure of labour productivity for the business sector which is defined as real value added per hours worked.

Figure 2 shows that annual growth in the estimates of aggregate labour productivity from T2-LEAP micro data file and the industry productivity database over the periods 1991 to 2000 and 2000 to 2014. Both estimates of aggregate labour productivity growth declined after 2000. Aggregate labour productivity of the business sector from the CPA declined from 2.96% per year for the period 1991 to

[1] The previous studies have used the t2-leap file to study the productivity dynamics of the non-manufacturing sectors (e.g. Baldwin and Gu, 2011, Gu and Lafrance, 2014)

2000 to 0.75% per year for the period 2000 to 2014. Aggregate labour productivity growth of the non-farm market sector from T2-LEAP showed a similar large decline after 2000, declining from 2.88% per year to 0.18% per year between the two periods.

The decline in labour productivity growth in Canada after 2000 have been well documented in previous studies (Baldwin and Willox, 2017, Gu, 2018, Sharpe and Tsang, 2018). The source of this large decline in labour productivity growth after 2000 has been examined using the growth accounting approach of Jorgenson and Griliches (1967) and Diewert (1976). The decline in labour productivity growth in Canada after 2000 was found to be mainly due to a decline in MFP growth after 2000. There is little change in the contribution of capital deepening effects. The decline in labour compositional effects after 2000 also contributed somewhat to the decline in labour productivity growth. Labour productivity growth declined in most industries. But the largest decline are in manufacturing sector and mining sectors (Gu, 2018)

The rapid productivity growth in 1990s in Canada is related to trade liberalization and the adoption of information and communication technologies. The slow productivity growth after 2000 is related to the slower growth in demand, 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 due to increased costs for extraction of the natural resource assets also contributed to the slow productivity growth in the 2000s (Gu, 2018).

3. Productivity Dispersion and Aggregate Productivity Growth

This section has two main objectives. First, it presents the trend in productivity growth of frontier and non-frontier firms. The productivity growth of frontier firms are commonly associated with innovation and technical progress. The productivity growth of non-frontier firms are associated with diffusion from frontier to non-frontier firms or catch up of non-frontier firms to frontier firms. Second, it decomposes aggregate productivity growth into contributions of frontier and non-frontier firms. The evidence on the contribution of frontier and non-frontier firms provides an assessment of the roles of innovation at frontier firms and diffusion from frontier to non-frontier firms to aggregate productivity growth over time and their contributions to the decline in productivity growth in Canada after 2000.

The analysis will focus two periods into 1991 to 2000 and 2000-2015. Some of changes in productivity growth are due to the cyclical factors arising from the changes in utilization of capital in the early 2000s and 1990s and slow growth in those two periods. The effect of capacity utilization changes

are concentrated in exporters, MNEs which tend to be the frontier firms (Baldwin, Gu and Yan 2013). Focusing a relatively long periods 1991 to 2000 and 2000 to 2015 will remove the effect of the cyclical factors on productivity growth and therefore provide an identification of the effects of structural factors such as innovation and technological diffusion on productivity growth.

Frontier firms are defined as the top 10% of the firms in terms of labour productivity levels within 3 digit level of classification according to North American Industry Classification 2007 (NAICS). All other firms within an NAICS 3-digit industry are defined as non-frontier firms. There are a total of 87 industries of the non-farm market sector at NAICS 3-digit level of industry aggregation. The productivity will be measured as the values in logarithm for the analysis of this section.

3.1. Productivity of Frontier and Non-frontier Firms

This section presents the productivity performance of frontier and non-frontier firms and changes in productivity dispersion in the non-farm market sector in Canada over 1991 to 2015. Both labour and multifactor productivity will be 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) will be presented for the period 1991 to 2015. MFP (gross output per unit of combined capital, labour and intermediate inputs) will be presented for the period after 2000 as the robust estimates of capital stock and intermediate inputs are only available after 2000.

The productivity of the frontier and non-frontier firms in logarithm is estimated as the median productivity values of each group. The log difference in productivity between the frontier and the non-frontier firms is used to measure productivity dispersion. The log difference in productivity between frontier and non-frontier firms at NAICS 3-digit level are aggregated to the log productivity difference at NAICS 2 digit level and at the non-farm market sector using a simple mean. Therefore, the log difference in productivity at NAICS 2-digit level or non-farm market sector represents the productivity dispersion in an average NAICS 3-digit industries.

Figure 3 presents labour productivity levels in logarithm for the frontier and non-frontier firms in the non-farm market sector over the period 1991 to 2015. Figure 4 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 figures. 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.

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

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 Figure 4. The productivity dispersion did not change much in the early 1990s and in the early 2000s. The pause in the overall trend towards productivity divergence between the frontier and non-frontier firms in the early 1990s and the early 2000s are found to due to the cyclical factors arising from slow demand growth and the decline in capacity utilization that affects exporters and multinationals more than that of other firms, at least in the manufacturing sector (Baldwin, Gu and Yan, 2013). The subsequent increase in productivity growth gap between the frontier and non-frontier firms in the second half of the 1990s and after 2009 are partially due to the increase in capacity utilization in the manufacturing, probably in other industries too (Gu, 2018).

To remove the effects of those cyclical factor and focus on the effects of structural factors such as innovation and diffusion on productivity growth, this paper will focus on productivity growth for the periods 1991 to 2000 and 2000 to 2015. The year 2000 corresponds the turning point with productivity growth in Canada declined.

Figure 5 present annual average growth in labour productivity of frontier and non-frontier firms for the periods 1991 to 2000 and 2000 to 2015. Labour productivity growth of frontier firms was higher than that of non-frontier firms in both periods. Labour productivity growth of frontier and non-frontier firms both declined after 2000. The decline was similar for both groups of firms. Labour productivity growth for both groups experienced about a one percentage point decline between two periods 1991 to 2000 and 2000 to 2015. Labour productivity growth of frontier firms declined from 3.43% per year in the period 1991 to 2000 to 1.05% per year in the period 2000 to 2015. Labour productivity growth of non-frontier firms declined from 2.44% per year to 0.51% per year between the two periods.

The productivity growth has been rapid before 2000 in Canada. The rapid progress in information and communication technologies (ICTs), the adoption of ICTs and associated changes in business organizations have been main force behind this rapid productivity growth (Gu and Willox, 2018; Ho, Rao and Tang, 2004). Trade liberation and the implementation of Canada-US free trade agreement and 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 has been high for the period 1991 to 2000.

Productivity growth declined after 2000. This suggests that the pace of innovation and the pact of diffusion from frontier to non-frontier firms both declined in Canada after 2000.

Figures 6, 7 and 8 compare the capital/labour ratio, intermediate input/labour ratio and MFP of frontier and non-frontier firms over the period 2000 to 2015. The frontier firms in those figures are defined as the top 10% of firms in terms of labour productivity levels.

Figure 6 shows that the capital/labour ratio increased for both frontier and non-frontier firms over the period 2000 to 2015. The increase was similar for frontier and non-frontier firms. Figure 7 shows that the intermediate input/labour ratio experienced little changes for both frontier and non-frontier firms from 2000 to 2015. As a result of the 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 period 2000 to 2015 was due the divergence in MFP between those two groups of firms, as shown in Figure 8.

Table 1 presents the labour productivity growth of frontier and non-frontier firms at NAICS 2-digit levels for the whole period 1991 to 2015. Table 2 and 3 presents their labour productivity growth in two sub-periods 1991 to 2000 and 2000 to 2015.

For the period 1991 to 2015, the labour productivity growth of frontier firms was higher than that of non-frontier firms in almost all industries except for three service industries: arts, entertainment and recreation; accommodation and food services; and other services. The biggest productivity growth difference between the frontier and non-frontier firms was in utilities, mining and oil and gas extraction, broadcasting and telecommunication, FIRE and wholesale and retail.

This labour productivity divergence occurred in both periods 1991 to 2000 and 2000 to 2015. The productivity growth gap between the frontier and non-frontier firms in the two periods are not correlated across industries. This suggests that the forces that shape the productivity divergence are unlikely to be related to the inherent characteristics of industries such as scale economies and the competitive intensity of the industries.

3.2. Contribution of Frontier and Non-frontier Firms to Aggregate productivity growth

This section decomposes aggregate productivity growth into contributions of frontier and non-frontier firms. The evidence on the contribution of frontier and non-frontier firms provides an assessment of the roles of innovation at frontier firms and diffusion from frontier firms to non-frontier firms (or catch-up of non-frontier firms to frontier firms) to aggregate productivity growth and their contributions to the decline in productivity growth in Canada after 2000.

The aggregate labour productivity growth in an industry can be decomposed into three components: contribution from the frontier firms, contribution from non-frontier firms and the 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:

$$p^t = s_1^t p_1^t + s_0^t p_0^1 ,$$

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 labour productivity of frontier firms in year t, and p_0^t is 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:

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

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 hand is the contribution of frontier firms to aggregate labour productivity growth which is estimated as the change in labour productivity of the frontier firms over two years multiplied by the shares of the frontier firms in total employment averaged over two years. The second term is the contribution of non-frontier firms to aggregate labour productivity growth that is equal to the change in labour productivity of the non-frontier firms multiplied by the shares of the non-frontier firms in total employment. The third term is the contribution of the share changes of frontier and non-frontier firms. This contribution is positive when there is shift in the shares of employment towards the frontier firms which tend to be more productive.

The decomposition is expressed in labour productivity in 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 adopted in labour productivity decomposition (see for example, Foster et al. 2001, Baldwin and Gu, 2006, OECD, 2017).

To ensure that the sum of three components in the decomposition 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 analysis of productivity dispersion of frontier and non-frontier firms in section 3.1 where the productivity of a group of firms is estimated as the median value of that group.

The decomposition of aggregate labour productivity into the contributions of frontier and non-frontier firms is done at NAICS 3 digit level. The results are then aggregated to NAICS 2-digit level and non-farm market sector using industry employment as weights.

Figure 9 presents the shares of frontier and non-frontier firms in employment and gross output in an average NAICS 2-digit industry. The frontier firms (defined as the top 10% of the firms in terms of labour productivity levels) accounted for about 30% of gross output. The share of the frontier firms in gross output was virtually unchanged over the period from 1991 to 2015.

The share of the frontier firms in total employment declined over time. The share of frontier firms in employment declined from 10% in 1991 to 6% in 2015. This suggests that the frontier firms were similar to non-frontier firms in size in terms of employment in 1991. But by 2015, the frontier firms were much smaller than non-frontier firms in term of employment.

The shares of frontier firms in employment and gross output differed across industries, as shown in Table 4. The frontier firms were smaller than the non-frontier firms in terms of employment in almost all industries except in the mining and oil and gas, manufacturing, and broadcasting and telecommunication industries.

When the size is measured by gross output, the frontier firms were larger than non-frontier firms in almost all industries except in accommodation and food services. In the food and accommodation service industry, the frontier firms were smaller than the non-frontier firms in terms of gross output.

Table 5 presents a decomposition of aggregate labour productivity growth in the non-farm market sector into the contributions of frontier and non-frontier firms. The frontier firms accounted for 11% of aggregate labour productivity growth in period 1991 to 2000 and the accounted for 9% of aggregate labour productivity growth in the period 2000 to 2015. The contributions of frontier firms to aggregate labour productivity was more than there shares of employment as a result 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 diffusion to aggregate labour productivity growth declined after 2000. The decline in innovation at the frontier firms and the decline in diffusion from frontiers 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. This suggests that the decline in the diffusion is more important contributor than the decline in innovation to post-2000 productivity slowdown in Canada.

Tables 6 and 7 present the decomposition of aggregate labour productivity growth into the contributions of frontier and non-frontier firms at NAICS 2-digit industries for period 1991 to 2000 and 2000-2015. Table 8 presents 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 almost all industries. Both frontier and non-frontier firms contributed to this decline in labour productivity as the productivity growth of both groups of firms declined after 2000 in almost all industries. This suggests that innovation and diffusion both declined contributing to the decline in productivity growth after 2000 in almost all industries in Canada.

Of course, the relative importance of innovation and diffusion for productivity growth is sensitive to the classification of frontier and non-frontier firms. But the overall conclusion that both decline in innovation and decline diffusion contributed to decline in productivity growth after 2000 is not sensitive to the classification. The same results hold when the frontier firms are defined as the top 5, top 15, or top 20% of the firms in terms of productivity levels.

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

4. Technical progress of frontier firms and catch up of non-frontier firms

This section uses a 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. Technical change from the stochastic frontier approach can be identified as

innovation and productivity growth of most efficient firms.[2] Technical efficiency change from the stochastic from frontier approach can be identified as the catch-up of non-frontier firms to frontier firms or the diffusion from frontier to non-frontier firms. The stochastic frontier approach provides an alternative decomposition of productivity growth into the contributions of innovation at the frontier firms and the diffusion from frontier to non-frontier firms.

The stochastic frontier production function establishes a statistical relationship between inputs and outputs for the most efficient of 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 measures the productivity of average firms relative to the frontier firms.

Specifically, the stochastic frontier production function can be written as

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

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

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

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

where y_{it} represents the logarithm of gross output of firm i in year t , x_{it} is a vector of input in logarithm, $dyear_t$ is full set of year dummies, $dind_n$ is a full set of industry dummies, $\alpha, \beta, and\ \gamma$ 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.

The coefficient estimates on the full set of year dummies and industries and interaction of year and industry dummies provide an estimate of shifts in frontier production function or technical progress of most productive firms in each year. Technical progress is allowed to differ across industries.

In the studies on productivity dispersion and productivity growth dynamics, the residual $\hat{\varepsilon}_{it}$ is interpreted as the productivity of average firms relative to the 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 $\hat{u}_{it}$

[2] Rada and Valdes (2012) adopted this to decompose the productivity growth of Brazilian agriculture it contributions from technical change and technical efficiency change.

measures the productivity of a firm relative to that of a frontier. The other component $\hat{v}_{it}$ represents measurement or specification errors. This paper 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 the 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 of industry dummies for NAICS 2-digit industries and interaction of year and industry dummies. [3]

The estimated stochastic frontier model can be used to decompose aggregate labour productivity into two components: technical progress that represents the shifts in frontier production function, and technical efficiency change that represents the catch up of average firms to the production frontiers. The estimated coefficients on time dummies are used to measure the shift in production frontier or technical changes. 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 is equal to aggregate labour productivity growth.

The results are presented in Table 9. Labour productivity growth declined in the non-farm market sector declined after 2000. The decline is due to the decline in technical change and the decline in technical efficiency change after 2000. This can be interpreted as the evidence that the pace of innovation at frontier firms and the rate of diffusion from frontier firms to non-frontier firms both declined after 2000, contributing to the decline in aggregate labour productivity growth after 2000. This evidence from the stochastic frontier approach is consistent with the results from the decomposition results from the comparison of frontier and non-frontier firms.

While tangible assets are only available after 2000, total assets are available for the entire period 1991 to 2015. Total assets are found to be highly correlated with tangible assets across firms and will be used as measure of capital stock when estimating a stochastic frontier production function on gross output that includes labour and capital as inputs for the period 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 is similar to the results that only includes labour as inputs. Technical change and technical efficiency are found to have declined after 2000. This decline contributed to a decline in MFP growth after 2000.

[3] When industry dummies are defined at NAICS 3-digit level, it took much longer to estimate stochastic frontier model. But the results are similar.

5. Resource Reallocation and Aggregate Labour Productivity Growth

The aggregate productivity growth can increase when productivity increases within firms. Or it can increase if the share of employment and output in more productive firms increases and the share of employment and output fall in less productive firms. Decker and et al. (2016) found that such reallocation is happening to a lesser extent in the post-2000 period, particularly in the high-tech sector, with implications for overall productivity growth.

This section will decompose aggregate labour productivity growth into the contribution from productivity growth occurring within firms and the contribution from the reallocation of employment between firms. For that purpose, the Olley and Pake decomposition will be adopted (Olley and Pakes, 1996)

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

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

where p_t is 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 labour productivity level of firm i in year t, and s_{it} is share of firm i in total employment in year t. A bar over a period is simple unweighted mean of that variable in that industry. In the decomposition, labour productivity is measured in levels. To implement this OP decomposition, labour productivity will be measured in log terms.

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

Figure 9 presents the trend in OP covariance term. As labour productivity is measured in logs, the changes in OP covariance measures the gains in labour productivity from reallocation. The figure presents two measures of OP covariance term. The first measure is calculated at NAICS 2 digit level and then

aggregated to total non-farm market sector using employment as weights. The second measure is calculated as NAICS 3 digit level and then aggregated to total non-farm market sector. The both measures show similar trend.

There was an increase in the effect of reallocation in the 1990s as labour is reallocated towards the firms with relatively higher labour productivity levels. The reallocation occurs as employment shifts 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, tech bubble in that period. After the financial crisis, there is an increase in the effect of reallocation on labour productivity growth.

The recession of the early 1990s in Canada is associated with an increase in the effect of reallocation on productivity growth possibly due to the cleansing effect of the recession that drives out the least efficient firms, while the slow growth of the early 2000s is associated with a decline in the effect of reallocation possibly due to distortions to reallocation dynamics during the slow growth period of the early 2000s. This evidence for Canada is broadly consistent with that for the U.S. in Foster, Grim and Haltiwanger (2016).

Overall, the improved re-allocation at NAICS 3 digit level contributed 0.70% per year to aggregate labour productivity growth for the period 1991 to 2000 (Table 10). The improved reallocation at NAICS 2 digit level contributed 0.6% per year to aggregate labour productivity growth. The effect of reallocation on aggregate productivity growth was essentially zero over the period 2000 to 2015, which reflects an increasing reallocation effect in the late 2000s that was more than offset by the declining reallocation effect before the financial crisis of 2008-2009.

This suggests that a part of the decline in aggregate labour productivity growth after 2000 was due to a decline in the contribution of resource reallocation after 2000. This is consistent the evidence there seems to be a decline in business start-ups and business dynamics in Canada over time and the decline contributed to the decline in aggregate labour productivity growth after 2000.

6. Conclusions

Productivity growth slowed in Canada since 2000s. This paper examines the causes of the productivity slowdown in Canada. It has two main objectives. First, it examines the role of innovation and technical progress at the frontier firms and the diffusion of innovation and technical progress from the frontier firms to the non-frontier firms for the decline in productivity growth after 2000. Second it

examines the role of changes in business dynamism and changes in misallocation for the productivity slowdown. The main findings are as follows.

First, labour productivity growth of frontier firms was higher than that of non-frontier firms in both periods. But labour productivity growth of frontier and non-frontier firms both declined after 2000. This suggests that the pace of innovation and the pace of diffusion from frontier to non-frontier firms both declined in Canada after 2000.

Second, the contributions of frontier and non-frontier firms to aggregate labour productivity growth declined after 2000. The decline in innovation at the frontier firms and the decline in diffusion from frontiers to non-frontier firms both contributed to the productivity slowdown after 2000 in Canada. But most of the decline in aggregate labour productivity growth is from the decline in the contribution of non-frontier firms. The decline in the diffusion is more important contributor than the decline in innovation to post-2000 productivity slowdown in Canada.

A stochastic frontier analysis that decomposes 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. It finds that the decline in aggregate labour productivity is due to the decline in technical change and the decline in technical efficiency change after 2000. This can be interpreted as the evidence that the pace of innovation at frontier firms and the rate of diffusion from frontier firms to non-frontier firms both declined after 2000, contributing to aggregate labour productivity slowdown after 2000.

Third, the improved re-allocation contributed significantly to aggregate labour productivity growth for the period 1991 to 2000, but the effect of reallocation was essentially zero over the period 2000 to 2015. The part of decline in aggregate labour productivity growth after 2000 was due to the decline in the contribution of resource reallocation after 2000, which is consistent the evidence there seems to be a decline in business start-ups and business dynamics in Canada over time and the decline contributed to the decline in aggregate labour productivity growth after 2000.

In sum, the decline in aggregate labour productivity growth in Canada after 2000 is found to be due to a decline in innovation at the frontier firms, a decline in diffusion from frontier to non-frontier firms and a decline in the effect of reallocation and business dynamism on productivity growth.

The evidence in this paper supports the OECD view that a main cause of the productivity slowdown is a slowing of the pace of diffusion from frontier firms to non-frontier firms or a breakdown of the diffusion machine which took place sometime in the early 2000s (OECD 2015). While innovation at the

frontier firms declined after 2000, the exact causes of this decline is not known. On the one hand, this could be evidence in support of Gordon (2016) that current technological advances such as mobile technology, the internet, and clouding computing are not great enough to drive strong productivity growth. On the other hand, the slow pace of innovation at frontier firms after 2000 is temporary and the new digital economy has yet to generate gains in productivity (van Ark, 2017).

References

Adler et al. (2017), "Gone with the Headwinds: Global Productivity," IMF Staff Discussion Note.

Aigner, D., C. Lovell, and P. Schmidt (1977), "Formulation and Estimation of Stochastic Frontier Production Function Models," Journal of Econometrics 6:21-37.

Andrews D., Criscuolo C. & Gal P. N. (2015), "Frontier Firms, Technology Diffusion and Public Policy: Micro Evidence from OECD Countries," OECD Productivity Working Papers N° 2, OECD Publishing.

Baily, Martin Neil, and Nicholas Montalbano (2016), *Why is Productivity Growth so Slow? Possible Explanations and Policy Responses*, Brookings Institution.

Baldwin, J.R., and W. Gu (2004), "Trade Liberalization: Export-market Participation, Productivity Growth, and Innovation," *Oxford Review of Economic Policy*, vol. 20, issue 3, pp. 372-392..

Baldwin, J.R., and W. Gu (2006), "Plant Turnover and Productivity Growth in Canadian Manufacturing," *Industrial and Corporate Change*.

Baldwin, J.R., and W. Gu (2011) "Firm Dynamics and Productivity Growth: A Comparison of Retail Trade and Manufacturing Sectors," *Industrial and Corporate Change*.

Baldwin, J.R., W. Gu, and B. Yan (2013) "Export Growth, Capacity Utilization and Productivity Growth: Evidence for Canadian Manufacturing Plants," *Review of Income and Wealth.*

Bartelsman, Eric and Zoltan Wolf (2017), "Measuring Productivity Dispersion," Tinbergen Institute Discussion Paper.

Cao, Shutao, Mohanad Salameh, Mai Seki, and Pierre St-Amant (2017). Trends in Firm Entry and New Entrepreneurship in Canada. Canadian Public Policy XLIII, III: 202–221.

Cette, Gilbert, Simon Corde and Rémy Lecat (2017), "Stagnation of Productivity in France: A Legacy of the Crisis or a Structural Slowdown?" working paper, Banque de France.

Decker, A. Ryan, John Haltiwanger, Ron S. Jarmin, and Javier Miranda (2016), Declining business dynamism: Implications for productivity, Brookings Institution.

Diewert, W.E. (1976), "Exact and Superlative Index Numbers," Journal of Econometrics. 4. 115-145

Fernald, J. (2015), "Productivity and Potential Output before, during and after the Great Recession," *NBER Macroeconomic Annual*, 2014, Vol. 29.

Foster, Lucia, Cheryl Grim, John Haltiwanger (2016), "Reallocation in the Great Recession: Cleansing or Not?" *Journal of Labour Economics*, vo. 34(S1): 293-331.

Foster, Lucia, Cheryl Grim, John Haltiwanger, and Zoltan Wolf (2016), "Firm-Level Dispersion in Productivity: Is the Devil in the Details?" *American Economic Review*, 106(5): 95-98.

Foster, Lucia, John Haltiwanger and C.J. Krizan (2001), "Aggregate Productivity Growth: Lessons from Microeconomic Evidence," in New Developments in Productivity Analysis, edited by Charles R. Hulten, Edwin R. Dean and M. J. Harper, NBER Book Series Studies in Income and Wealth.

Gordon, R. (2016), *The rise and fall of American growth: The US standard of living since the Civil War*, Princeton University Press.

Gu, W. (2018) "Accounting for Slower Productivity Growth in Canada after 2010: The Role of Capital Measurement Issues" *International Productivity Monitor,*

Gu, W. and M. Willox (2018), "Productivity Growth in Canada and the United States: Recent Trends and Potential Explanations," paper presented at the 2018 annual meeting of the Canadian Association of Economics, Montreal, Canada.

Gu, W. and A Lafrance (2014), "Productivity Growth in the Canadian Broadcasting and Telecommunications Industry: Evidence from Micro Data," Economic Analysis Research Paper Series no. 89. Statistics Canada.

Haldane, Andrew G. (2017), "Productivity Puzzles," London School of Economics.

Ho, M. H., S. Rao and J. Tang (2004), Sources of Output Growth in Canadian and U.S. Industries in the Information Age, in *Economic Growth in Canada and the United States in the Information Age*, edited by Dale. W. Jorgenson, Industry Canada Research Publications Program, Ottawa. Canada.

Jorgenson, D.W. and Z. Griliches (1967), "The Explanation of Productivity Change," Review of Economic Studies, Vol. 34, No. 3, pp. 249–283.

Macdonald, Ryan, (2014) "Business Entry and Exit Rates in Canada: A 30-year Perspective. Statistics Canada," Statistics Canada

Manyika, James, et al. (2017), "The Productivity Puzzle, A Closer Look at the United States," Mckinsey Global Institute, Discussion Paper.

Meeusen, W., and J. Van den Broeck (1977), "Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error," International Economic Review (18) no. 2: 435-44

OECD (2015), *The Future of Productivity*, OECD Publishing

OECD (2017), *The Multiproduct Project: A Comprehensive Review*, OECD.

Olley, G.S and A. Pakes (1996), "The Dynamics of Productivity in the Telecommunications Equipment Industry", *Econometrica*, 64(6), pp. 1263-97.

Rada, Nicholas, and Constanza Valdes (2012), "Policy, Technology, and Efficiency of Brazilian Agriculture," Economic Research Report no. 137. US Department of Agriculture.

Rao, S. and J. Li (2013), "Explaining Slower Productivity Growth: the Role of Weak Demand Growth," *International Productivity Monitor*, Fall 2013.

Sharpe. A. and S. Murray (2018), "The Explanations of the U.S. Productivity Slowdown," International Productivity Monitor.

Sharpe, A. and W. K. Tsang, (2018), "Stylized Facts about Slower Productivity Growth in Canada", paper presented at CSLS-Productivity Partnership Workshop on "Explaining Canada's Post-2000 Productivity Performance" McGill University, Montreal, Canada, May 31- June 2, 2018.

Syverson, Chad (2011), "What Determines Productivity?" Journal of Economic Literature, 49(2): 326-65.

Trefler. D. (2004), "The Long and Short of the Canada-US Free Trade Agreement," *American Economic Review*, vol. 94, no. 4, pp. 870-895.

Tukey, J.W. (1977), *Exploratory Data Analysis*, Addison-Wesley, Reading, MA

van Ark, Bart, 2016, "The Productivity Paradox of the New Digital Economy," *International Productivity Monitor*. Fall 2016.

Figure 1. Aggregate Labour productivity in Canada, 1991 to 2015, 1991=100

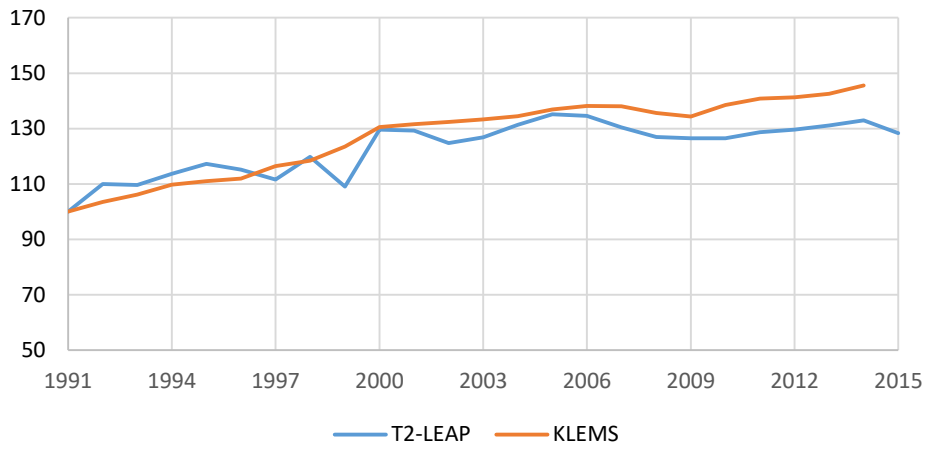


Figure 2. Annual average growth in aggregate labour productivity in Canada (% per year)

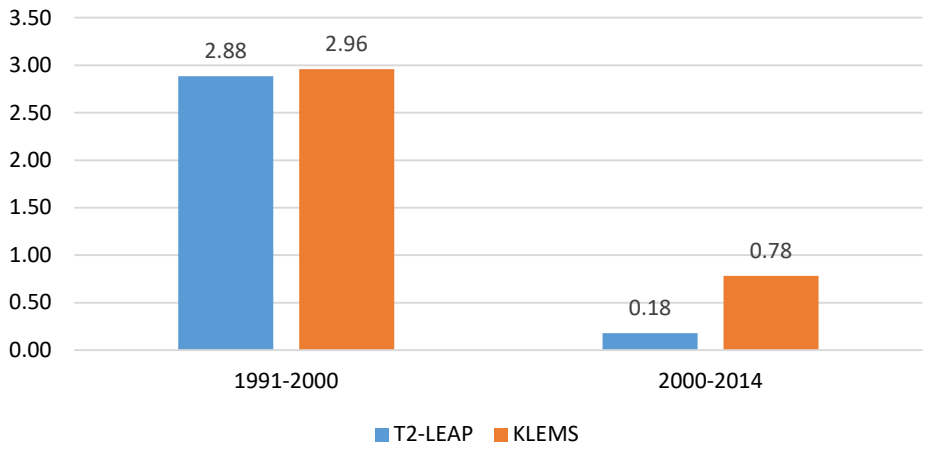


Figure 3. Labour productivity of frontier and non-frontier firms, 1991 to 2015 in logarithm and 0 in 1991

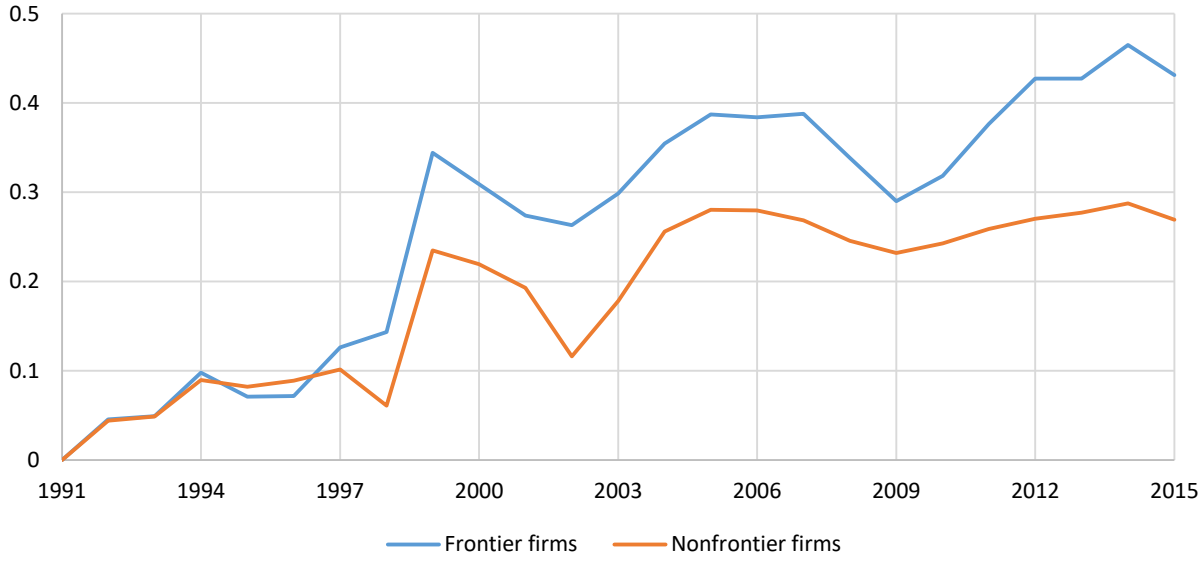


Figure 4. Relative labour productivity in logarithm of the frontier and non-frontier firms, 0 in 1991, 1991 to 2015

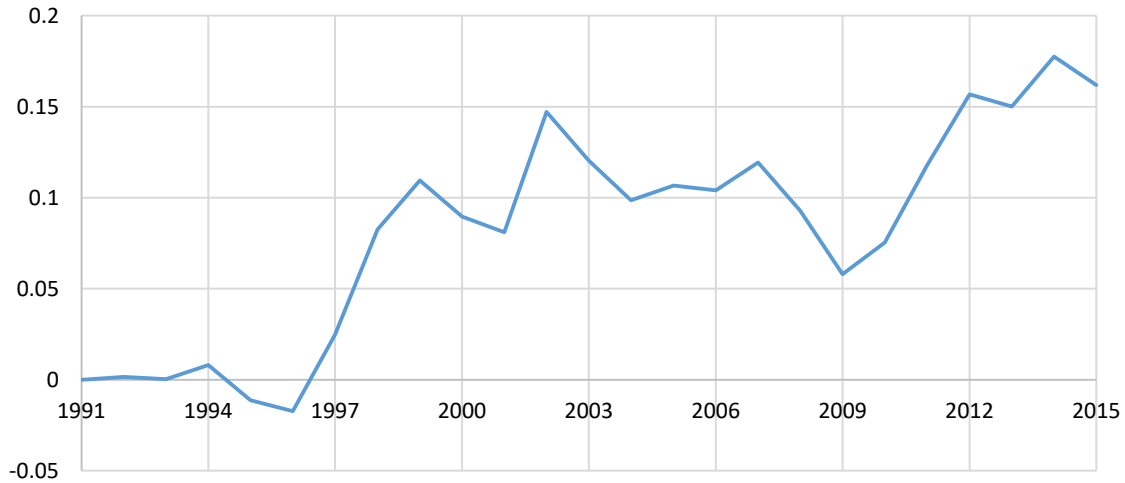


Figure 5. Aaverage labour productivity growth of frontier and non-frontier firms (% per year), 1990 to 2000 and 2000 to 2015

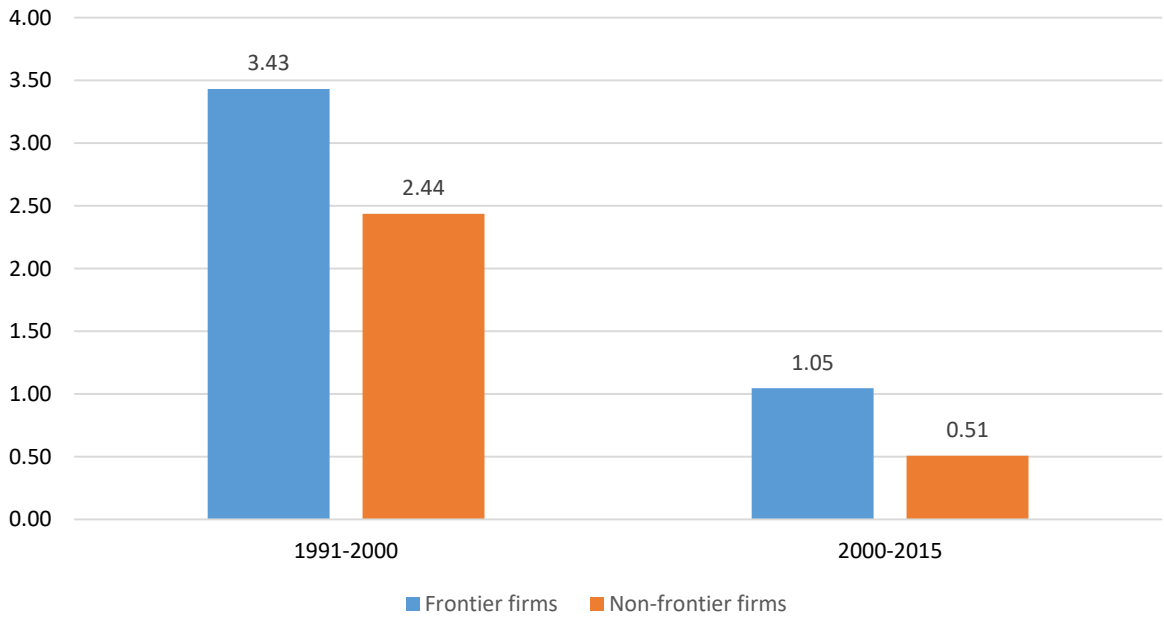


Figure 6. Capital/labour ratio of frontier and non-frontier firms, 2000 to 2015, in logarithm and 0 in 2000

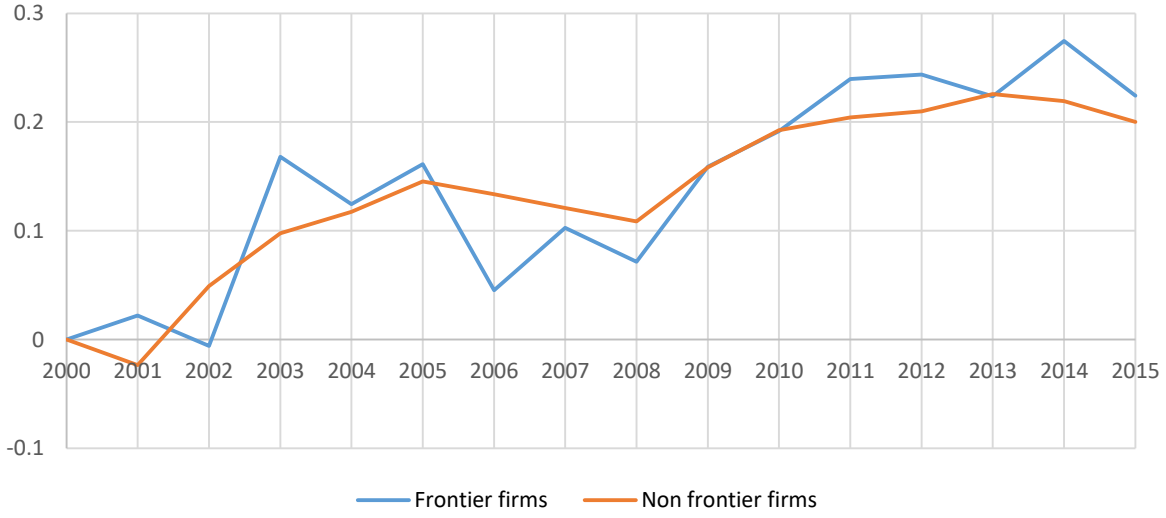


Figure 7. Intermediate input/labour ratio of frontier and non-frontier firms, 2000 to 2015, in logarithm and 0 in 2000

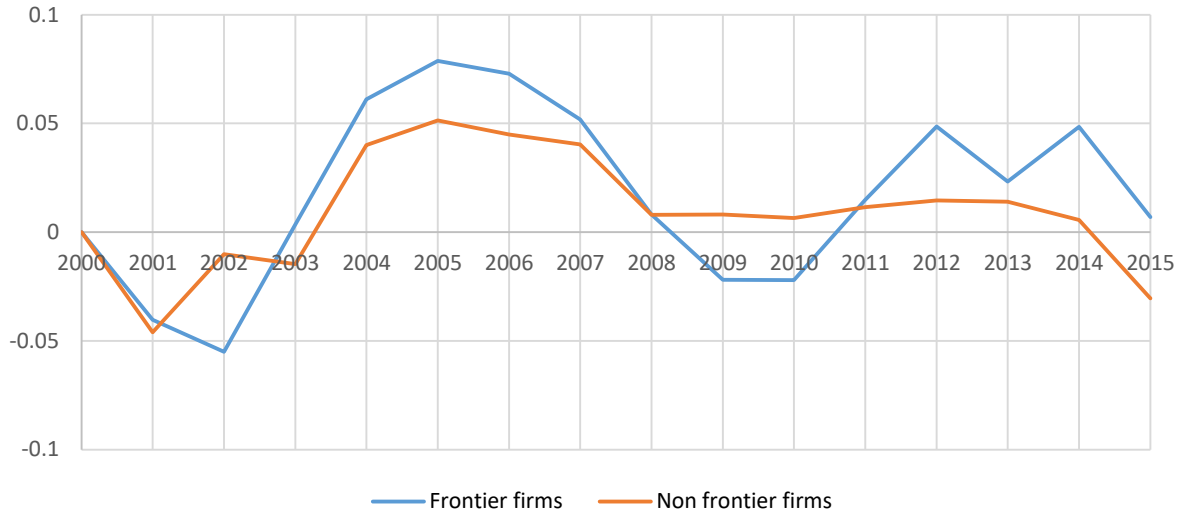


Figure 8. MFP of frontier and non-frontier firms, 2000 to 2015
in logarithm and 0 in 2000

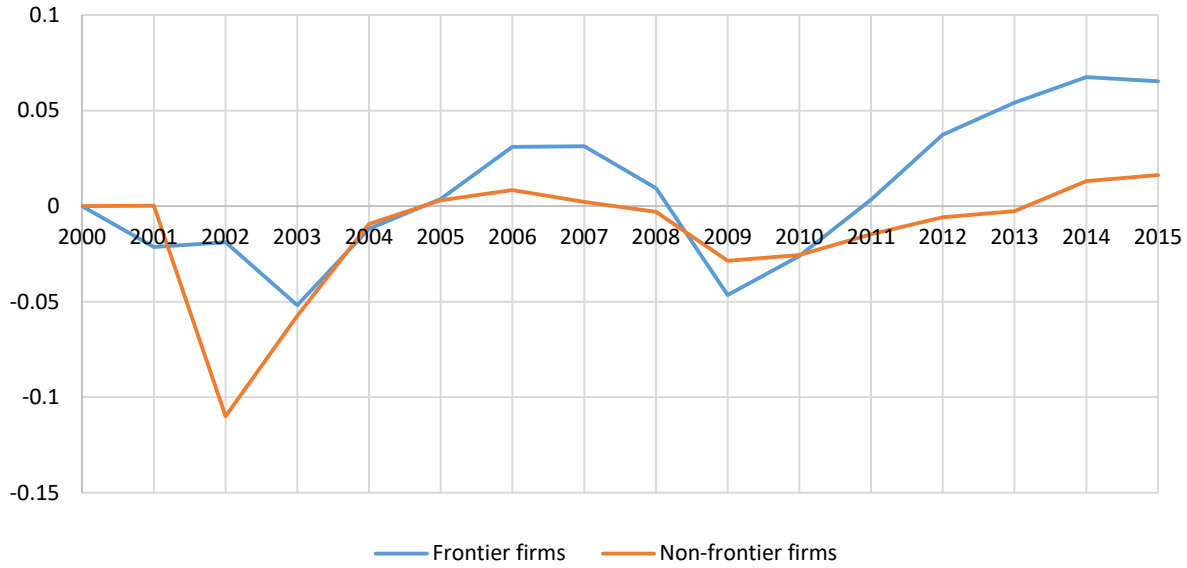
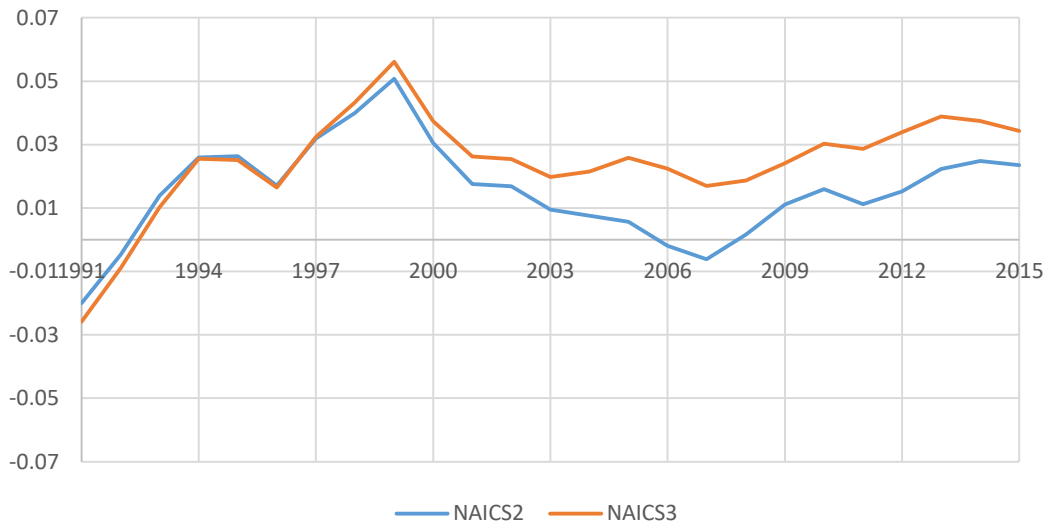


Figure 9. The percent share of frontier firms in employment and gross output 1991 to 2015

Figure 10. OP Covaraince term in non-farm market sector, 1991 to 2015



Note. The chart presents a 3 year moving average of the OP covariance term.

Table 1. Annual average labour productivity growth of frontier and non-frontier firms by industry, 1991 to 2015 (% per year)

	Frontier firms	Non-frontier firms	Frontier less non-frontier
Mining and oil and gas	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	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 telecommunication	2.05	0.49	1.55
FIRE	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	1.80	1.12	0.67

Table 2. Annual average labour productivity growth of frontier and non-frontier firms by industry, 1991 to 2000 (% per year)

	Frontier firms	Non-frontier firms	Frontier less non-frontier
Mining and oil and gas	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	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 telecommunication	4.57	1.35	3.23
FIRE	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	3.43	2.44	1.00

Table 3. Annual average labour productivity growth of frontier and non-frontier firms by industry, 2000 to 2015 (% per year)

	Frontier firms	Non-frontier firms	Frontier less non-frontier
Mining and oil and gas	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	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 telecommunication	2.99	2.23	0.76
FIRE	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	1.05	0.51	0.54

Table 4. The percent share of frontier firms in employment and gross output, average over 1991 to 2015

	Share of employment	Share of output
Mining and oil and gas	16.54	43.67
Utilities	8.95	47.56
Construction	4.33	20.18
Manufacturing	17.21	48.11
Wholesale and retail	7.27	29.16
Transportation and warehousing	5.31	31.46
Information and culture	6.46	25.29
Broadcasting and telecommunication	12.70	36.86
FIRE	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	7.89	31.29

Table 5. Contributions of frontier and non-frontier firms to aggregate labour productivity growth (% per year), 1991 to 2000 and 2000 to 2015

	1991-2000	2000-2015	2000-2015 less 1991 to 2000
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

Table 6. Contributions of frontier and non-frontier firms to labour productivity growth by industry (% per year), 1991 to 2000

	Frontier firms	Non-frontier firms	Share changes	Labour productivity growth
Mining and oil and gas	0.95	3.41	-0.62	3.74
Utilities	1.79	-5.84	-5.57	-9.62
Construction	0.18	2.16	-0.10	2.24
Manufacturing	0.38	3.10	0.67	4.15
Wholesale and retail	0.55	4.98	-0.49	5.03
Transportation and warehousing	0.44	3.42	0.28	4.14
Information and culture	0.40	5.58	-0.25	5.74
Broadcasting and telecommunication	0.53	2.75	-0.92	2.35
FIRE	0.07	1.99	0.02	2.09
Arts, entertainment and recreation	0.41	0.94	0.26	1.61
Accommodation and food services	0.08	1.84	-0.08	1.85
Other services	0.18	4.05	-0.16	4.07
All	0.39	3.30	-0.14	3.55

Table 7. Contributions of frontier and non-frontier firms to labour productivity growth by industry (% per year), 2000 to 2015

	Frontier firms	Non-frontier firms	Share changes	Labour productivity growth
Mining and oil and gas	0.29	-3.00	-0.92	-3.63
Utilities	-0.04	12.73	-0.48	12.21
Construction	-0.03	-0.32	-0.08	-0.43
Manufacturing	0.32	1.53	-0.04	1.82
Wholesale and retail	-0.17	-0.36	0.33	-0.19
Transportation and warehousing	-0.19	0.42	0.07	0.30
Information and culture	0.16	-0.46	0.05	-0.26
Broadcasting and telecommunication	0.13	0.72	-0.64	0.21
FIRE	0.05	0.08	-0.11	0.02
Arts, entertainment and recreation	-0.02	0.32	-0.05	0.25
Accommodation and food services	-0.02	-0.15	0.00	-0.18
Other services	0.10	0.95	-0.36	0.70
All	0.03	0.35	-0.04	0.34

Table 8. Contributions of frontier and non-frontier firms to decline in labour productivity growth by industry (% per year), 2000 to 2015 less 1991 to 2000

	Frontier firms	Non-frontier firms	Share changes	Labour productivity growth
Mining and oil and gas	-0.66	-6.41	-0.30	-7.37
Utilities	-1.84	18.58	5.08	21.83
Construction	-0.21	-2.48	0.02	-2.67
Manufacturing	-0.06	-1.57	-0.70	-2.33
Wholesale and retail	-0.72	-5.34	0.83	-5.23
Transportation and warehousing	-0.63	-3.00	-0.20	-3.84
Information and culture	-0.25	-6.04	0.30	-5.99
Broadcasting and telecommunication	-0.39	-2.03	0.28	-2.14
FIRE	-0.02	-1.92	-0.13	-2.07
Arts, entertainment and recreation	-0.43	-0.62	-0.31	-1.36
Accommodation and food services	-0.11	-1.99	0.07	-2.03
Other services	-0.08	-3.10	-0.20	-3.38
All	-0.36	-2.95	0.10	-3.21

Table 9. Technical changes, technical efficiency changes and aggregate labour productivity growth

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

Table 10. Reallocation, within-firm growth, and aggregate labour productivity growth (% per year)

	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 OP co-variance term for estimating the contribution of reallocation is calculated at NAICS 3 digit level of industry classification.