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Plant Dynamics and Productivity of the Canadian Petroleum and Coal Product Manufacturing Industry

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Abstract: The Canadian petroleum and coal product manufacturing industry primarily engages in transforming crude petroleum and coal into intermediate and end products. The dominant production is petroleum refining, which involves the separation of crude petroleum into component products through such techniques as cracking and distillation. The petroleum and coal products manufacturing industry is one of the industries with the weakest productivity performance in Canada in the post 2000 period. This paper assesses the structural change and plant dynamics facing the Canadian industry in such an environment with increasingly demand for energy products and unconventional deposits being extracted and processed, and discusses the industrial policy implications for the productivity performance of this industry.

Keywords: Plant dynamics, productivity, petroleum and coal manufacturing

JEL codes: L10, L20, O30

1. Introduction

The Canadian petroleum and coal product manufacturing industry primarily engages in transforming crude petroleum and coal into intermediate and end products. The dominant production is petroleum refining, which involves the separation of crude petroleum into component products through such techniques as cracking and distillation. This industry has seen considerable growth in the past decade in terms of nominal revenue; manufacturing revenue nearly quadrupled from $16.3 billion in 1998 to $59.2 billion in 2009, after peaking at $84.0 billion in 2008. The phenomenal expansion in revenue, however, has not been driven by an increase in value added. Instead, it has mainly been due to an increase in the cost of intermediate inputs. Over the 1998-2009 period, manufacturing cost, which includes expenses on materials and supplies such as fuel and electricity, increased from $13.1 billion in 1998 to $50.4 billion in 2009. Value added was virtually unchanged over this period, recorded at about $3.2 billion (Industry Canada 2008).

The stagnation in value added reflects the weak productivity performance of this industry. Over the 1998-2009 period, labour productivity in the industry, defined as real value added per hour worked, declined on average 3.2 percent per year. The weak productivity performance has contributed to Canada’s overall weak productivity performance in the business sector, a subject of continuing interest for Canadian policymakers (e.g., Boothe and Roy, 2008; Lynch and Sheikh, 2011). The increasing level of concern surrounding the subject is hardly a surprise, given the direct impacts of productivity on living standards and in a nation with ageing population.

For many, it is the reported divergence in productivity performance between Canada and its chief competitor and foreign market, the U.S. that is the central concern behind this trend, because productivity performance is directly linked to international competitiveness. Prior works, using industry-level data, have identified the petroleum and coal product manufacturing as having experienced, since 2000, a growing gap in productivity between Canada and the U.S.. For example, Almon and Tang (2011) shows that labour productivity in the industry over the 2000-2008 period declined 2.6 percent per year in Canada while in the U.S. it grew 8.4 percent per year.

This paper studies the sources of the weak productivity performance of the petroleum and coal product manufacturing in the post-2000 period. It assesses the productivity implications of the structural change experienced by the Canadian petroleum and coal products manufacturing industry, in an environment with increasing demand for energy products and marginal/unconventional deposits being extracted and processed. In essence, it investigates the role of changes in industry mix and plant dynamics, as well as the impact of changes in product mix and the increased use of low-quality material inputs (e.g., unconventional oil), in the weaker productivity performance of this industry. It addresses four research questions:

(1) Is the weak productivity performance wide-spread across sub-industries of the petroleum and coal product manufacturing industry in Canada, and how does this compare to the U.S. experiences?

(2) Which group of plants (continuing plants, entrants or exits) is driving the results in Canada?

(3) Does resource reallocation between industries or plants contribute to the weak productivity performance of this industry?

(4) Finally, do changes in product/input mix have important implications for measured productivity?

To address those questions, this paper relies on both growth accounting and econometric analyses. For the first question, it decomposes the industry aggregate productivity performance into pure productivity effect and industry-composition effect at the sub-industry level. The decomposition analysis is done for both Canada and the U.S. The remaining analysis is done only for Canada, due to data limitations. For questions (2) and (3), it further decomposes sub-industry productivity performance into three components: productivity performance of continuing plants, resource allocation between continuing plants, and net entry. Finally, for question (4), it uses econometric analysis to estimate if changes in product/input mix affect labour productivity performance at the plant level, after controlling for other factors such as fuel and power consumption per unit of labour (a proxy for capital intensity), foreign ownership, and plant size.

The industry analysis will use detailed industry level data in Canada and the U.S. for 1997-2006, extracted from their micro data from their Annual Survey of Manufacture (ASM) programs. A discussion of the data is in section 3.

2. The petroleum and coal product manufacturing at a glance

In this section, we provide an overall view of the petroleum and coal products manufacturing industry, and brief on how it differs from other industries.

The petroleum and coal products manufacturing industry accounted for 3.6 percent of total manufacturing value added, but only 1.6 percent of total manufacturing hours worked in Canada in 2008. It is one of highly capital intensive manufacturing industries. It is also intermediate input intensive, heavily dependent on raw petroleum and coal for materials. In 2007, the ratio of materials and supplies to gross output was 81.2 percent while, for the overall manufacturing sector, it was 57.4 percent.[1]

The petroleum and coal product manufacturing industry is less dynamic than most of other manufacturing industries in terms of plant turnover. For instance, in 1997-2000, the entry and exit rates were 12 percent and 6 percent respectively for the petroleum and coal product manufacturing. In contrast, for transportation equipment manufacturing, they were 37 percent and 23 percent and for computers and electronic manufacturing, they were 41 percent and 25 percent (Chan, Gu and Tang, 2011, 2012). The lower turnover rate for the industry largely reflects the large fixed/sunk cost for both entry and exit.

Crude oils can be used to produce a large variety of petroleum products. Demand for the types of output products may change with technological developments or consumer preferences, while cost structure for producing different products may depend on the refining technology available and the quality of the raw petroleum input, whether it is conventional oil or unconventional oil.

In Canada, the petroleum refinery industry's geographical distribution has significant effects on the types of crude oil received and the product mix produced (Natural Resources Canada 2009). In Western Canada and Ontario, most refineries are designed to process light sweet crude oil extracted in Western Canada. These refineries take in about 50 percent light, sweet crude oil, 25 percent high quality synthetic crude oil from upgraded tar sands bitumen, and the reminder is mostly heavy, sour crude oil. Refineries in Atlantic Canada and Quebec receive a more diverse variety of imported crude oils of varying quality. These refineries are facing fewer constraints on their crude oil sources. In contrast, in the U.S., refineries are more flexible, and they are designed to accept larger percentages of heavy, high sulphur crude oil, and have invested in more complex technology to process lower quality crude oil. There is evidence that the Canadian petroleum and coal product manufacturing industry invested less in M&E than its U.S. counterpart since 1987, although the gap narrowed somewhat in the post-2000 period (figure 1).

On the output side, different geographical regions also have different demand mixes in petroleum and coal products (Natural Resources Canada, 2009). In Atlantic Canada, light heating oil is the primary source of home heating, and medium distillates account for about 40 percent of petroleum product demand. Heavy fuel oil for electric generation also accounts for 24 percent of demand, while gasoline is less than 30 percent. Medium distillate demand is also high in Western Canada, at 40 percent for agricultural purposes. Outside Atlantic Canada, gasoline demand is higher, from 40 percent in Western Canada and Quebec to over 45 percent in Ontario, but electric generation is less dependent on heavy oil.

Refinery technology is a major factor in determining refinery products. U.S. refineries use technology that yields higher percentages of gasoline and a lower quantity of heavy oil because of high gasoline demand in the U.S. In Canada, gasoline yield is lower, due to higher medium distillate demand, but still higher than Europe, where distillate demand is high for diesel automobiles.

Saviotti, et al. (2005) finds that changes in demand variety and increased diversification in refining technology are closely related. They show that, before the first oil shock around 1978, the number of discernible technologies increased but the degree of process variety was decreasing, suggesting more incremental changes in diversity. After 1978, the number of technologies and the degree of variety both increased significantly. The oil shock spurred innovation, both from pressure to lower costs due to increased materials cost and from demand for new petroleum products caused by changes in technologies used by petroleum product-using goods, such as transportation equipment and chemicals.

3. Data and measurement issues

For our analyses, we make use of the data that are collected by the Census of Manufactures programs in the two countries, which are quite similar in collecting data on outputs and inputs. The Canadian data are from a longitudinal file constructed from the micro-records of Statistics Canada's Annual Survey (Census) of Manufactures (ASM). The file covers the entire Canadian manufacturing sector using both survey and administrative data, and permits plants and firms to be followed over time. It collects data on manufacturing value added and employment, together with other variables. There were 54544 manufacturing plants in 2006, increased from 48881 in 1997. For the petroleum and coal product manufacturing industry, there were 317 plants in 2006, increased from 231 in 1997.

For the U.S., we obtain data for total value added and employment from the U.S. Bureau of Census. These data are at the very detailed industry level (six-digit NAICS level). They are also aggregated from the micro-records of the U.S. ASM administrated by the U.S. Bureau of Census.

For Canada, we have the access to the ASM micro data on both products and inputs at the commodity level, which allows us to further explore the linkage between productivity and product/input mix. These types of data only cover the recipients of the ASM long form, consisting of all larger establishments as well as a fraction of smaller establishments. The threshold for defining which establishment receive the long form or short form varies by year and industry. In 2000, about 45 percent of all manufacturing establishments, representing 90 percent of shipment value, received the long form. This data is available for 1990-2006, though the data for 1991 is incomplete.

Commodity classification schemes change over time. Of the ASM micro-files available, four schemes have been used: the 1988 Industrial Commodity Classification (ICC) for 1990-1997, the 1996 Standard Classification of Goods (SCG) for 1997-1999, the 2000 SCG for 2000-2003, and the 2004 ASM List of Goods for 2002-2006. Of these classifications, the 1988 ICC, 1996 SCG and 2000 SCG are generally comparable for the petroleum and coal product industry. However, the 2004 ASM List of Goods classification is considerably more aggregated than the other classifications, and therefore not comparable.

The petroleum and coal product manufacturing industry consists of four six-digit sub-industries (table 1), which is the most detailed industry level that does not compromise the confidentiality requirement at Statistics Canada.

The definition of labour productivity used in the analysis is real value added per employee. Due to data limitations, nominal values added in the U.S. are deflated using the deflator for the petroleum and coal products as a whole from U.S. Bureau of Economic Analysis. For Canada, they are deflated using deflators at the four-digit industry level from Statistics Canada.

For our analysis, we choose the 1997-2006 period, over which we have data for both Canada and the U.S. The industry mix and plant turnover effects on aggregate productivity growth are examined for two sub-periods: 1997–2000 and 2000–2006. We use 2000 as a dividing point, as it was frequently used in the literature for studying Canada's productivity performance. For our input mix and product mix analysis, we choose the 1990-2003 period, excluding 1991, over which we have consistently detailed commodity level data.

To improve the comparability over time and between the two countries, we made several adjustments to the industry level data obtained from the ASM data for both Canada and the U.S. First, the ASM data may not be entirely comparable over time due to change in industry classification (e.g., from 1997 NAICS to 2002 NAICS) and in sampling methodology. For instance, for Canada, the micro-records of the ASM for the 1997-1999, the 2000-2003, and the 2004-2006 sub-periods are drawn from different populations.

Second, "value added" from the ASM is often referred to as "census value added," and is inclusive of payments for purchased services, which is used as intermediate inputs for production. The inclusion of purchased service in the analysis matters since the increased trend in outsourcing in services activities in the manufacturing industry and the trend development may differ between Canada and the U.S. In addition, it does not include the output from those who are self-employed, which may be different between the two countries.

Third, "census value added" for Canada is manufacturing census value added while for the U.S., it is total census value added. The latter consists of both manufacturing census value added and value added from merchandising operations (i.e., the difference between the sales value and the cost of merchandise sold without further manufacture, processing, or assembly).

Finally, the number of employees from the ASM is not exactly equal to the number of employees used by the statistical agencies to produce the official productivity statistics. Among other things, it needs to add those that are classified as being self-employed. In addition, we need to adjust employment to hour worked to reflect the change in work intensity over time.

To make ASM data more comparable to official national accounts and between Canada and the U.S., we benchmark the aggregate employment and value-added obtained from the ASM to the data on hours worked and value-added from Statistics Canada's productivity program for Canada (CANSIM tables 383-0021 and 383-0009).[2] For the U.S., the data census value added and employment from the U.S. ASM are benchmarked to the data on value-added from the industry accounts of the U.S. Bureau of Economic Analysis and hours worked for all persons from the U.S. Bureau of Labor Statistics, respectively. Due to data availability, the adjustment is made at the four-digit level for Canada and at the three-digit level for the U.S.

4. Empirical analysis on the industry mix effect in Canada and the U.S.

Before we proceed to discuss the decomposition results for the industry mix effect, we first briefly describe the profile of the industrial structure of the petroleum and coal product manufacturing industry in Canada, with a comparison to its U.S. counterpart.

4.1. The industrial structure of the petroleum and coal manufacturing industry in Canada and the U.S.

The largest sub-industry in the Canadian petroleum and coal product manufacturing industry was petroleum refineries. The sub-industry's nominal value added share increased from 66.2 percent in 1997 to 80.3 percent in 2006 (table 2). In terms of employment, however, its share was relatively stable at 55 percent over this period (table 3).

For the U.S., the industrial structure is remarkably similar, although the share of petroleum refineries in the U.S. was even larger in both nominal value added and employment.

For both countries, the most productive petroleum and coal product manufacturing sub-industry is petroleum refineries (table 2). This sub-industry in Canada produced 20 percent more of value added per hour worked than the average for the petroleum and coal product manufacturing in 1997 and the productivity advantage increased to 33 percent in 2006. In the U.S., the productivity difference is more pronounced, with the sub-industry being 35 percent more productive than the industry average in 1997 and 47 percent in 2006.

4.2. The productivity effect of industry structural shift

Following the technique, as shown in Appendix A, in our early work on transportation equipment industry, we decompose aggregate labour productivity growth for the petroleum and coal product manufacturing industry in both Canada and the United States over 1997–2000 and 2000–2006. The first component is called pure productivity growth effect, capturing industrial contributions purely due to industrial labour productivity improvements. The second component is the industry reallocation effect, reflecting an industry composition shift towards sub-industries with relatively high productivity and/or relatively high productivity growth. We first discuss the Canadian experiences and then compare them to the U.S.

Canada

As shown in table 4, the productivity changes in the Canadian petroleum and coal product manufacturing industry in those two sub-periods were dominated by pure productivity changes within constituent industries and not by reallocation.

In 1997–2000, for the petroleum and coal product manufacturing industry as a whole, labour productivity increased by 1.2 percent per year. The improvement was entirely due to the pure productivity growth effect, which was offset slightly by a small negative contribution from the reallocation effect. The largest contributor for the pure productivity growth effect was petroleum refineries. Over this period, petroleum refineries also became more important than other sub-industries in the petroleum and coal product manufacturing industry, driven by increased value of its products relative to the value of products produced by other sub-industries. However, the positive shift was more than matched by a negative shift in other sub-industries, especially asphalt paving and shingle and coating materials. As a result, the overall reallocation effect was a small negative.

The picture in the post-2000 period is completely different. For the petroleum and coal product manufacturing industry as a whole, labour productivity in Canada declined by 2.8 percent per year. This was a decline of 4.0 percentage points compared to 1997-2000. This decrease in growth was driven mainly by the pure productivity growth term, which fell by 3.8 percentage points.

Among the sub-industries, the decline in productivity growth can be solely attributed to petroleum refineries. Its contribution fell from 4.8 percentage points in 1997-2000 to -2.2 percentage points in 2000-2006, a decline of 7.0 percentage points. For the sub-industry, both the productivity and reallocation effects fell, and were equally responsible for the productivity growth slowdown in the petroleum and coal product manufacturing industry. On the other hand, the contributions from the other sub-industries improved over these two periods (ranged from 0.9 percentage points to 2.2 percentage points), mainly due to a favourable change in industry reallocation.

U.S.

Unlike in Canada, labour productivity growth in the U.S. petroleum and coal product manufacturing accelerated from 7.5 percent per year in 1997-2000 to 11.2 percent in 2000-2006 (table 5). The productivity growth acceleration was almost entirely driven by petroleum refineries. For the sub-industry, its total contribution increases from 6.3 percentage points in 1997-2000 to 9.9 percentage points in 2000-2006, largely due to acceleration in pure productivity growth in this sub-industry.

4.3. Counterfactual analysis

As discussed in section 4.1, the Canadian and U.S. petroleum and coal product manufacturing industries are somewhat different in industry mix. Most notably, the U.S. is concentrated more in petroleum refineries than in Canada (tables 2 and 3).

In this sub-section, we examine how industry structure differences affect the productivity performance of the petroleum and coal product manufacturing industry in Canada, using a counterfactual analysis. To this end, we replace Canadian sub-industry output and employment shares by corresponding U.S. output and employment shares in the decomposition, keeping the values of other variables as before.

The counterfactual analysis shows that the productivity profile of the Canadian petroleum and coal product manufacturing industry would grow almost at the same pace as before (table 6). Therefore, the counterfactual analysis suggests that the differences in industry structure of the petroleum and coal product manufacturing industry between Canada and the U.S. are not a factor for the weaker productivity performance of the industry in Canada than in the U.S.

5. Empirical analysis on the plant turnover in Canada

In this section, we deepen our investigation for Canada by examining the role played by plant turnover in the productivity performance of each sub-industry. To this end, for each period from *t-1* to *t*, we divide the participants in each sub-industry into three groups: continuing plants, entrants and exits. Continuing plants are those existing in both *t-1* and *t*. Entrants are plants that exist only in *t*, while for exits, they exist in *t-1*, but not in *t*. Because of this disaggregation, we have to combine some of the sub-industries to meet Statistics Canada's non-confidential conditions. In particular, we combine petroleum refineries (324110) and other petroleum and coal products (324190) into "petroleum refineries and other petroleum and coal products", and asphalt paving mixture and block (324121) and asphalt shingle and coating materials (324122) into "asphalt paving, roofing and saturated materials". As a result, we end up with two broad sub-industries.

5.1. Plant turnover in the Canadian petroleum and coal manufacturing industry

Following the analysis on industry mix, here we discuss and compare plant turnover in two periods: 1997-2000 and 2000-2006.

1997-2000

In the pre-2000 period, exiting plants made up 6 percent of the 1997 plant population, and entering plants made up 12 percent of the 2000 plant population (table 7). There was a net increase in the number of plants. However, this was driven by asphalt paving, roofing and saturated materials sub-industries where the entering rate (14 percent) was more than double the exiting rate (5 percent). For petroleum refineries and other petroleum and coal products, the entering and exiting rates were the same at 9 percent.

Over this period, continuing plants' average employment expanded by 5 percent (table 8). For entrants and exits, they were typically smaller than continuing plants. They employed about 26 percent and 57 percent, respectively, of the employment of continuing plants in 1997-2000. There was more dispersion in the size of exits across sub-industries. Exits were very small in petroleum refineries and other petroleum and coal products (only 38 percent of continuing plants), but much large in asphalt paving, roofing and saturated materials (153 percent of continuing plants). Similarly, the size of entrants varied significantly across sub-industries. It was very small for petroleum refineries and other petroleum and coal products, but relatively large for asphalt paving, roofing and saturated materials.

Entrants and exits were both less productive than continuing plants in this period (table 9). Exits were 56 percent less productive than the continuing plants in 1997 and entrants were 67 percent less productive than the continuing plants in 2000. Over this period, continuing plants improved productivity by a meagre 4 percent. The pattern was similar across the sub-industries.

2000-2006

In the pre-2000 period, exiting plants made up 14 percent of the 2000 plant population while entering plants made up 13 percent of the 2006 population (table 7).[3] Because there were fewer entrants than exits, the plant population decreased during the period.

For the industry as a whole, continuing plants increased employment by an average of 5 percent over the second period (Table 8). As in 1997–2000, entrants and exits in 2000-2006 were on average smaller than continuing plants, and they were 21 percent and 18 percent of continuing plants in employment, respectively. However, there was a large dispersion in employment size across sub-industries. Employment of exiting plants was 8 percent of continuing plants in petroleum refineries and other petroleum and coal products, and 47 percent in asphalt paving, roofing and saturated materials. For entering plants, their average employment was 8 percent of the continuing plants in petroleum refineries and other petroleum and coal products and 58 percent in asphalt paving, roofing and saturated materials.

On average, exits were 65 percent less productive and entrants were 53 percent less productive than continuing plants (Table 9). At the sub-industry level, however, there is a great variation in the productivity of both exits and entrants. Both entrants and exits in petroleum refineries and other petroleum and coal products were about 80 percent less productive than continuing plants. In contrast, both entrants and exits in asphalt paving, roofing and saturated materials were almost as productive as continuing plants.

Productivity of continuing plants increased slightly by 1 percent over this period. The improvement in productivity was pervasive across all sub-industries.

5.2. The productivity effect of plant turnover

As shown in table 4, the decline in labour productivity growth in the Canadian petroleum and coal product manufacturing industry between the pre-2000 and post-2000 periods was mainly from the decline in productivity growth at the sub-industry level. The effect is referred to as the pure productivity growth effect, which is equal to the weighted sum of labour productivity growth of the sub-industries, with the weight being the nominal output share of each sub-industry at the beginning of each period.

In this section, we decompose labour productivity growth at the sub-industry level into components associated with continuing plants, entrants and exits, following Griliches and Regev (1995) or the GR decomposition, which is described in Appendix B. The results are reported in table 10. A positive number for entrants (exits) represents the entrants (exits) being on average more (less) productive than the industry average, and vice versa. The component related to net entry is the sum of the components for entrants and exits.

The GR decomposition results show that the dramatic decline in labour productivity growth in continuing plants (the within continuing plant effect) between pre-2000 and post-2000 periods was entirely responsible for the dramatic decline in productivity growth in the Canadian industry.[4] The decline in productivity growth of continuing plants was large in the two sub-industries. On the other hand, the effect from resource reallocation between continuing plants was positive, but the magnitude was too small to offset the negative within continuing plant effect. The within and continuing effects, combined, suggest that among continuing plants, there is a shift toward plants or production techniques of high productivity level. The contribution from net entry was slightly negative since the positive entry was completely offset by negative exit, especially in the asphalt paving, roofing and saturated materials.

6. The productivity implication of input/output mix

The composition of crude oil production in Canada has changed significantly, moving from conventional oil to unconventional oil (table 11). This is because conventional oil production is now in the final stages of depletion in most mature oil fields, and oil production is moving to unconventional sources.

Conventional oil is an oily mixture of hydrocarbons recoverable at a well from an underground reservoir at atmospheric pressure and temperature. On the other hand, unconventional oil is extracted using techniques other than the traditional oil well method. Currently, a major focus of non-conventional oil production in Canada is on oil sands in northern Alberta. It is on a large scale, mainly using steam-assisted drainage technologies (SAGD – steam-assisted gravity drainage).

The crude bitumen extracted from oil sands is a viscous form and deficient in hydrogen. It is more expensive than conventional crude oil to process and refine into more useful petroleum products, such as gasoline, diesel fuel, asphalt base, heating oil, kerosene, and liquefied petroleum gas. To make it an acceptable feedstock for conventional refineries, it must be upgraded through the addition of hydrogen or the rejection of carbon (at on-site upgraders to high-quality synthetic crude oil or SCO). In order to transport bitumen to refineries equipped to process it, bitumen must be blended with diluents, traditionally condensate, to meet pipeline specifications for density and viscosity. Although upgrading is a costly process, it has become commercially viable due to increasing oil prices.[5]

As discussed in the introduction, the nature of the business of the petroleum and coal product manufacturing industry is closely linked to raw material inputs and sensitive to the geographic location of the raw materials being produced. The quality of the materials input to the petroleum and coal products manufacturing varies, with petroleum ranging from high quality light sweet conventional crude to low quality unconventional crude bitumen that requires upgrading (at on-site upgraders to synthetic crude oil or SCO) or dilution (to be transported by pipeline to refineries).

Because of the abundance and development of oil sands in Canada, it is natural to think of that the Canadian manufacturing industry may have increased the use of low quality unconventional crude oil as its petroleum input. This may have important implications for productivity performance of this industry.[6]

Does the development in the upstream industry, the oil and gas extraction, affect the productivity performance of petroleum refineries? To shed light on this question, we first look at the change in the composition of crude oils feed into petroleum refineries (table 12). Yes, the composition of crude oils feed into petroleum refineries has changed, increasingly towards to unconventional oils. But, the change was much slower than the case in crude oil production. In addition, the increasingly use of unconventional oils has been based on synthetic oils, which are high quality light crude oils derived from upgrading bitumen from oil sands. The actual use of crude bitumen for refineries has been insignificant and has virtually unchanged in the past 25 years. It is also interesting to note the use of heavy conventional crude oil, which is closer in quality to bitumen, is also in decline in the post-2000 period.

Why are Canadian petroleum refineries not processing more unconventional oils to keep the pace of the Canadian oil producers? The answer to this question may have to do with two facts. First, oil refineries and oil extraction are not proportionally located in the same geographical locations. Petroleum refineries are roughly spread from the west to the east while oil extraction is dominated by the west, especially Albertan and Saskatchewan, despite a significant increase in oil extraction in Atlantic Provinces mainly due to the Hibernia oil field (table 13), and it is too expensive to ship crude oil from the west to the east. Second, most existing Canadian petroleum refineries are lacking in investment in retooling to accommodate heavier crude, which leads to limited capacity to process low quality crude bitumen (the Conference Board of Canada, 2011).[7] As a result, Canadian petroleum refineries rely heavily on imported conventional crude oils (table 14).

The discussion so far has been on industry average and firm-specific results may be averaged out. To prove or disprove the hypothesis, we deepen our analysis into the firm level, the ASM files with commodity data for both input and output, as discussed before.

The shifting from high quality raw material inputs to lower quality raw material inputs is expected to reduce productivity. This is because it is difficult to process lower quality materials, which often requires more other inputs (i.e., labour, capital and energy). To be worse, a refinery may not be unable to process crude oil of other specifications that are not designed for without some significant investment.

To measure the quality of crude oil inputs for petroleum refineries, we use the shares of unconventional crude oil in total intermediate inputs, grouping unconventional crude oil into synthetic crude oil and other unconventional crude oil such as bitumen from oil sands. As shown in table 12, the share of unconventional crude oil in total crude oil refined in Canada is small. It was 24 percent in 2010, increased from 13 percent in 1990. Most of the increase is due to the increased use of synthetic crude oil, from 11 percent in 1990 to 21 percent in 2010. The share of other unconventional crude oil, including bitumen, has been stable at about 2 percent over the period.

Productivity may also be linked to input/output varieties. An increase in the choice of material inputs is likely to increase productivity since production organization becomes more flexible. It allows producers to match their input mix more precisely to the desired technology or product characteristics (Tybout, 2006).

For output variety, a decrease in output variety may indicate specialization and concentrate in the core, which is positive for productivity. On the other hand, a plant's productivity may be positively correlated with the number of products it produces. Bernard, Redding, and Schott (2010), for instance, find that multiple-product firms have higher measured revenue-based productivity than single-product firms because the former group are able to cover the fixed costs with a greater number of products.

To measure input/output variety, we use the Herfindahl index (normalized to range between zero and one):

$$H = \frac{\sum S_k^2 - 1/n}{1 - 1/n} \qquad (1)$$

where $S_k = R_k / R$ is the share of product (input) line *k* in total revenue (raw material costs) and *n* is the number of product (input) lines. A small number means variety and a large number means concentration.

Input and output variety indexes are reported in table 15. It shows that input variety seems to be stable in petroleum refineries and that output variety increases. For asphalt paving mixture and block, input variety decreases while output variety increases.

To establish the linkage between productivity and product/input mix, we estimate the following regression model:

$$\ln(P_{i,t}) = \beta_0 + \beta_1 \ln(E_{i,t}) + \beta_2 F_{i,t} + \beta_3 \ln(S_{i,t}) + \beta_4 HQ_{i,t} + \beta_5 LQ_{i,t} + \beta_6 \ln(OD_{i,t}) + \beta_7 \ln(ID_{i,t}) + \sum_j \beta_{7+j} I_{i,j} + \sum_k \beta_{9+k} T_k + \varepsilon_{i,t} , \quad (2)$$

where $\ln(P_{i,t})$ is defined as value-added per worker (in logarithm);

$\ln(E_{i,t})$ is fuel and power consumption per worker (in logarithm), a proxy for capital intensity;

$F_{i,t}$ is a foreign ownership dummy variable, which equals one if it is foreign-controlled;

$S_{i,t}$ is plant size relative to its industry average in terms of employment;

$HQ_{i,t}$ and $LQ_{i,t}$ are the shares of unconventional high and lower quality crude oil;

$OD_{i,t}$ and $ID_{i,t}$ are output and intermediate inputs diversification;

$I_{i,j}$ is an industry dummy, 1 for plant *i* belonging to industry *j* and 0 otherwise;

T_k is a year dummy, 1 for year *k* and 0 otherwise; and

$\varepsilon_{i,t}$ is the error term.

Using the ASM data for 1990 and 1992-2003, we run the above regression model for different combinations of variables associated with input and output mix. There are several interesting results emerging from the regressions (table 16). First, productivity is positively related to unconventional synthetic crude oil input and negatively associated with other unconventional crude oil inputs. The result for unconventional synthetic crude oil is expected, given that unconventional synthetic crude oil is a high quality light crude oil derived from upgrading bitumen from oil sands and other unconventional sources. The negative relationship between productivity and other unconventional crude oil inputs is also expected, given those inputs are of lower quality and difficult to process.

We find that neither input nor output variety is associated with productivity. The result may be due to the fact that what input mix can be used and what output mix can be produced in the Canadian petroleum and coal manufacturing industry are largely constrained to the installed capital and technology. This is evidenced by the fact both input and output variety indexes were very stable over the period 1999-2003. It is also consistent with our early discussion that suggests that inputs to refineries are not really following what crude oil being extracted in Canada.

7. Concluding remarks

The petroleum and coal products manufacturing industry is one of the industries with the weakest productivity performance in Canada in the post-2000 period, and the productivity gap with its U.S. counterpart has been widening significantly.

This paper shows that the dramatic decline in productivity growth in the Canadian petroleum and coal products manufacturing industry and the widening productivity between Canada and the U.S. in the industry in the post-2000 period were mainly due to the decline in productivity growth in Canadian petroleum refineries, which accounts for more than 80 percent of the Canadian petroleum and coal product manufacturing industry. Most of the decline in Canadian petroleum refineries can be traced to the decline in labour productivity growth of continuing plants. In addition, it is found that resources allocation between industries or between plants was not responsible for the weaker productivity performance of the Canadian petroleum and coal products manufacturing industry in the post-2000 period or relative to its U.S. counterpart.

This paper also shows that raw materials inputs into Canadian petroleum refineries seem not to be an important factor for the weak productivity performance. Although unconventional crude oil, other than synthetic, is negatively associated with productivity and oil extraction in Canada has substantially moved to unconventional sources such as oil sands, petroleum refineries in Canada have been continuing to refine and process conventional crude oil or high quality unconventional oil such as synthetic, either because Canadian refineries are unable to process low quality unconventional crude oil or because geographic constraints.

The fact that Canadian refineries are older and less flexible than those in the U.S. as they are only used to processing lighter, sweeter oil might have contributed their weaker productivity performance, particularly the divergence of negative Canadian productivity growth after 2000 versus positive U.S. productivity growth. Using more expensive lighter and sweeter crude oil requires less refinery upgrading, but supplies of the crude oil are decreasing (Natural Resources Canada 2009). If a Canadian refinery is to adapt to lower value oil sands, it must invest in more expensive methods of processing.

Low output growth of the petroleum and coal product industry may also be a factor in slowing productivity growth. Nominal value added has remained stable from 1999 to 2008 at about $3.2 billion (Industry Canada 2008). Low output growth, combined with a lack of investment in upgrading the technology necessary to process lower quality crude oil, may create excess capacity that has contributed to low productivity growth.

This paper has largely focused on the plant dynamics and its contribution to productivity growth in the petroleum and coal products manufacturing industry. What are underlying causes for the productivity growth slowdown of continuing plants in the petroleum refineries in the post-2000 period and why was there divergence in productivity growth in the industry between Canada and the U.S.? These questions have, to a large extent, not been answered. To successfully address these questions, micro data on investment in capital and innovation, together with the change in market conditions for the petroleum and coal products, for both Canada and the U.S. may be the key.

Appendix: Decomposition techniques

7.1. Analytical framework for industry mix

According to Chan, Gu and Tang (2011), the productivity growth for the petroleum and coal products manufacturing industry as a whole can be decomposed into two components at its sub-industry level:

$$g(Z_t) = \sum_i w_{t-1}^i g(Z_t^i) + \sum_i \tilde{z}_{t-1}^i \left[1 + g(Z_t^i)\right]\Delta s_t^i, \qquad \text{(A1)}$$

where $g(Z_t) = (Z_t - Z_{t-1})/Z_{t-1}$ and Z_t is labour productivity, defined as real output per hour worked for the petroleum and coal product manufacturing in year *t*,

w_{t-1}^i is the nominal output share of sub-industry *i* in the petroleum and coal product manufacturing industry in the beginning year, *t*-1,

$\tilde{z}_{t-1}^i = Z_{t-1}^i / Z_{t-1}$, the labour productivity level of industry *i* relative to the aggregate labour productivity level at the beginning of the period, and

$\Delta s_t^i = s_t^i - s_{t-1}^i$, the change in the relative size of industry *i* from *t-1* to *t* and $s^i = p^i l^i$, the labour input share of sub-industry *i*, adjusted for its relative output price.

The first term is the *pure productivity effect*, which equals the sum of the weighted industrial labour productivity growth rates, and the weight for each sub-industry is equal to its nominal output share at the beginning of the period. The effect captures industrial contributions purely due to industrial labour productivity improvements.

The second term is the *reallocation effect*, which equals the sum of the weighted changes in relative size, and the weight for each sub-industry is equal to its relative labour productivity at the beginning of the period, adjusted for labour productivity growth. Note that a change in relative size in this paper reflects the change in importance of an industry in an economy, which could be due to a change in labour input share or relative output price. The reallocation effect makes a positive contribution to productivity growth if a shift in importance is towards industries of relatively high productivity and/or relatively high productivity growth.

7.2. Analytical framework for plant turnover

According to Griliches and Regev (1995) (or the GR decomposition method), the productivity change of sub-industry *i*, $\Delta Z_{t,t-1}^i = Z_t^i - Z_{t-1}^i$, can be further decomposed at the plant level. It divides plants three groups: continuing plants (set *C*), entrants (set *E*), and exits (set *X*). Continuing plants are those existing in both *t-1* and *t*. Entrants are plants that exist only in *t*, while for exits, they exist in *t-1,* but not in *t*.

With the grouping, the productivity change for sub-industry i can be decomposed four components associated with the three groups:

$$\Delta Z_{t,t-1}^{i} = \sum_{j \in C} \bar{s}^{ij}(Z_t^{ij} - Z_{t-1}^{ij}) + \sum_{j \in C}(s_t^{ij} - s_{t-1}^{ij})(\bar{Z}^{ij} - \bar{Z}^{i}) + \sum_{j \in E} s_t^{ij}(Z_t^{ij} - \bar{Z}^{i}) - \sum_{j \in X} s_{t-1}^{ij}(Z_{t-1}^{ij} - \bar{Z}^{i}) \tag{B1}$$

where over-lined variables represent the two-period average between *t-1* and *t*, and $\bar{Z}^{i}$ is the two-period average industry productivity.

The first term is the within-plant contribution from productivity change in continuing plants. The within term is independent of input allocation changes and reflects solely on improvements on the productivity performances of plants.

The second term is the between-plant contribution and captures the effects of shifting in employment shares by continuing plants. This term is positive when plants that gain employment share are more productive than the industry average, and plants that lose employment share are less productive than the industry average.

The last two terms are the effects of entering and exiting plants, respectively. Like the between term, productivity of entrants and exits are compared with the industry average. When entrants are more productive than the industry average, their entry will have a positive effect on the productivity performance of this industry. Similarly, when exits are less productive, then their exit will also have a positive effect.

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Table 1. The Sub-industries of the petroleum and coal products manufacturing industry in Canada and the U.S.

Industries	NAICS code
Petroleum and coal manufacturing	**324**
Petroleum refineries	324110
Asphalt paving mixture and block	324121
Asphalt shingle and coating materials	324122
Other petroleum and coal products	324190

Other petroleum and coal products manufacturing (NAICS: 32419) includes coke oven products, fireplace logs, hydraulic fluids and petroleum, lubricating oils and greases, and waxes, and petroleum products made from used refined petroleum.

Table 2. Output share and relative labour productivity level in the Canadian and U.S. petroleum and coal product manufacturing industries, 1997–2006

Industries	Nominal output share			Relative labour productivity level		
	1997	2000	2006	1997	2000	2006
Canada						
Petroleum and coal manufacturing	**100.0**	**100.0**	**100.0**	**1.00**	**1.00**	**1.00**
Petroleum refineries	66.2	79.2	80.3	1.20	1.26	1.33
Asphalt paving mixture and block	7.4	4.9	6.6	0.56	0.60	0.69
Asphalt shingle and coating materials	13.0	8.1	9.3	1.22	1.17	1.09
Other petroleum and coal products	13.3	7.8	3.7	0.64	0.39	0.23
U.S.						
Petroleum and coal manufacturing	**100.0**	**100.0**	**100.0**	**1.00**	**1.00**	**1.00**
Petroleum refineries	82.1	83.6	88.4	1.35	1.36	1.47
Asphalt paving mixture and block	5.2	5.0	3.5	0.41	0.39	0.23
Asphalt shingle and coating materials	5.4	5.1	3.0	0.44	0.41	0.26
Other petroleum and coal products	7.2	6.4	5.1	0.52	0.47	0.39

Table 3. Relative size of the Canadian and U.S. petroleum and coal products manufacturing industries, 1997–2006

Industries	Employment share			Relative output price			Relative size		
	1997	2000	2006	1997	2000	2006	1997	2000	2006
Canada									
Petroleum and coal manufacturing	**100.0**	**100.0**	**100.0**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Petroleum refineries	55.2	56.6	54.4	1.00	1.11	1.11	0.55	0.63	0.61
Asphalt paving mixture and block	13.3	13.6	16.5	1.00	0.60	0.58	0.13	0.08	0.10
Asphalt shingle and coating materials	10.7	11.5	14.7	1.00	0.60	0.58	0.11	0.07	0.09
Other petroleum and coal products	20.8	18.3	14.4	1.00	1.11	1.11	0.21	0.20	0.16
U.S.									
Petroleum and coal manufacturing	**100.0**	**100.0**	**100.0**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Petroleum refineries	60.8	61.3	60.2	1.00	1.00	1.00	0.61	0.61	0.60
Asphalt paving mixture and block	13.0	12.8	15.4	1.00	1.00	1.00	0.13	0.13	0.15
Asphalt shingle and coating materials	12.4	12.5	11.5	1.00	1.00	1.00	0.12	0.12	0.12
Other petroleum and coal products	13.8	13.4	12.9	1.00	1.00	1.00	0.14	0.13	0.13

Table 4. Industry contribution to labour productivity growth in the Canadian petroleum and coal products manufacturing industry, 1997–2000 and 2000-2006

Industries	Labour productivity growth rate (% per year)	Contribution		
		Total	Pure productivity growth	Reallocation
1997-2000				
Petroleum and coal manufacturing	**1.2**	**1.2**	**1.4**	**-0.3**
Petroleum refineries	2.9	4.8	1.9	3.0
Asphalt paving mixture and block	4.2	-0.8	0.3	-1.1
Asphalt shingle and coating materials	0.7	-1.4	0.2	-1.6
Other petroleum and coal products	-6.6	-1.5	-0.9	-0.6
2000-2006				
Petroleum and coal manufacturing	**-2.8**	**-2.8**	**-2.4**	**-0.4**
Petroleum refineries	-1.8	-2.2	-1.5	-0.7
Asphalt paving mixture and block	-0.6	0.1	-0.1	0.2
Asphalt shingle and coating materials	-1.7	0.0	-0.4	0.4
Other petroleum and coal products	-3.7	-0.7	-0.5	-0.2

Table 5. Industry contribution to labour productivity growth in the U.S. petroleum and coal products manufacturing industry, 1997–2000 and 2000-2006

Industries	Labour productivity growth rate (% per year)	Contribution		
		Total	**Pure productivity growth**	**Reallocation**
1997-2000				
Petroleum and coal manufacturing	7.5	7.5	7.4	0.1
Petroleum refineries	7.4	6.3	6.2	0.1
Asphalt paving mixture and block	11.3	0.4	0.4	0.0
Asphalt shingle and coating materials	8.6	0.4	0.4	0.0
Other petroleum and coal products	10.4	0.4	0.5	0.0
2000-2006				

Petroleum and coal manufacturing	11.2	11.2	11.2	0.0
Petroleum refineries	13.0	9.9	10.0	-0.1
Asphalt paving mixture and block	2.5	0.4	0.2	0.2
Asphalt shingle and coating materials	5.4	0.3	0.4	0.0
Other petroleum and coal products	10.0	0.6	0.7	-0.1

Table 6. Counterfactual industry contribution to labour productivity growth in the Canadian petroleum and coal products manufacturing industry, using U.S. output and employment shares

Industries	Labour productivity growth rate (% per year)	Contribution		
		Total	Pure productivity growth	Reallocation
	1997-2000			
Petroleum and coal manufacturing	**1.7**	**1.7**	**1.7**	**0.0**
Petroleum refineries	2.9	5.0	2.1	2.9
Asphalt paving mixture and block	4.2	-0.9	0.2	-1.0
Asphalt shingle and coating materials	0.7	-2.0	0.1	-2.1
Other petroleum and coal products	-6.6	-0.4	-0.7	0.2
	2000-2006			
Petroleum and coal manufacturing	**-2.4**	**-2.4**	**-2.3**	**-0.2**
Petroleum refineries	-1.8	-1.6	-1.3	-0.2
Asphalt paving mixture and block	-0.6	0.0	-0.1	0.1
Asphalt shingle and coating materials	-1.7	-0.3	-0.2	-0.1
Other petroleum and coal products	-3.7	-0.6	-0.6	0.0

Table 7. Percent of entering, continuing, and exiting plants in the Canadian petroleum and coal product manufacturing industry, 1997–2006

	1997–2000 Exiting plants (1)	1997–2000 Continuing plants (2)	1997–2000 Entering plants (3)	2000–2006 Exiting plants (4)	2000–2006 Continuing plants (5)	2000–2006 Entering plants (6)
Petroleum and coal product	**6**	**94**		**14**	**86**	
		88	**12**		**87**	**13**
Petroleum refineries and other	9	91		18	82	
petroleum and coal products		91	9		86	14
Asphalt paving, roofing and	5	95		11	89	
saturated materials		86	14		87	13

Note: (1) Average across years of share of plants that exited after 1997, 1998, and 1999, in those years' plant population (in percent?).

(2) Average across years of share of continuing plants in 1998, 1999, and 2000, compared with exits (top) and entrants (bottom).

(3) Average across years of share of plants that entered in 1998, 1999, and 2000, in those years' plant population.

(4) Average across years of share of plants that exited after 2000, 2001, 2002, 2003, 2004, and 2005, in those years' plant population.

(5) Average across years of share of continuing plants in 2001, 2002, 2003, 2004, 2005, and 2006, compared with exits (top) and entrants (bottom).

(6) Average across years of share of plants that entered in 2001, 2002, 2003, 2004, 2005, and 2006, in those years' plant population.

Table 8. Relative employment of entering, continuing, and exiting plants in the Canadian petroleum and coal product manufacturing industry, 1997–2006
(Average initial employment of continuing plants across years=1.00 in 1997 or 2000)

	1997–2000 Exiting plants (1)	1997–2000 Continuing plants (2)	1997–2000 Entering plants (3)	2000–2006 Exiting plants (4)	2000–2006 Continuing plants (5)	2000–2006 Entering plants (6)
Petroleum and coal product	**0.57**	**1** **1.05**	**0.27**	**0.18**	**1** **1.05**	**0.21**
Petroleum refineries and other petroleum and coal products	0.38	1 1.04	0.20	0.08	1 1.04	0.08
Asphalt paving, roofing and saturated materials	1.53	1 1.06	0.67	0.47	1 1.07	0.58

Note: (1) Average taken across years of the relative final year average hours employment of exiting plants in 1997, 1998 and 1999, relative to hours employment of that year's continuing plants.

(2) Average taken across years of the relative final year average hours employment of continuing plants in 1998, 1999 and 2000, relative to the average hours employment of those plants one year previously.

(3) Average taken across years of the relative starting year average hours employment of entering plants in 1998, 1999 and 2000, relative to hours employment of previous year's continuing plants.

(4) Average taken across years of the relative final year average hours employment of exiting plants in 2000, 2001, 2002, 2003, 2004 and 2005, relative to hours employment of that year's continuing plants.

(5) Average taken across years of the relative final year average hours employment of continuing plants in 2001, 2002, 2003, 2004, 2005 and 2006, relative to the average hours employment of those plants one year previously.

(6) Average taken across years of the relative starting year average hours employment of entering plants in 2001, 2002, 2003, 2004, 2005 and 2006, relative to hours employment of previous year's continuing plants.

Table 9. Relative productivity of entering, continuing, and exiting plants in the Canadian petroleum and coal product manufacturing industry, 1997–2006
(Average initial productivity of continuing plants across years=1.00)

	1997–2000 exiting plants (1)	1997–2000 continuing plants (2)	1997–2000 entering plants (3)	2000–2002, 2004–2006 exiting plants* (4)	2000–2002, 2004–2006 continuing plants* (5)	2000–2002, 2004–2006 entering plants* (6)
Petroleum and coal product	**0.44**	**1** **1.04**	**0.34**	**0.35**	**1** **1.01**	**0.47**
Petroleum refineries and other petroleum and coal products	0.50	1 1.06	0.38	0.18	1 1.01	0.20
Asphalt paving, roofing and saturated materials	0.40	1 0.95	0.41	0.91	1 1.01	1.00

Note: (1) Average taken across years of the relative final year average productivity of exiting plants in 1997, 1998 and 1999, relative to productivity of that year's continuing plants.

(2) Average taken across years of the relative final year average productivity of continuing plants in 1998, 1999 and 2000, relative to the average productivity of those plants one year previously.

(3) Average taken across years of the relative starting year average productivity of entering plants in 1998, 1999 and 2000, relative to productivity of previous year's continuing plants.

(4) Average taken across years of the relative final year average productivity of exiting plants in 2000, 2001, 2002, 2004 and 2005, relative to productivity of that year's continuing plants.

(5) Average taken across years of the relative final year average productivity of continuing plants in 2001, 2002, 2004, 2005 and 2006, relative to the average productivity of those plants one year previously.

(6) Average taken across years of the relative starting year average productivity of entering plants in 2001, 2002, 2004, 2005 and 2006, relative to productivity of previous year's continuing plants.

*Entrant and continuing plant output data censored at the sub-industry level in 2003.

Table 10. Plant-level GR decomposition of labour productivity growth of constituent industries in the Canadian petroleum and coal product manufacturing industry, 1997-2000 and 2000–2006

	Labour productivity growth rate	Within continuing plants	Between continuing plants	Net entry	Entering plants	Exiting plants
1997-2000						
Petroleum refineries and other petroleum and coal products	1.26	1.59	-0.32	-0.01	-0.74	0.73
Asphalt paving, roofing and saturated materials	3.69	4.30	-3.10	2.49	0.55	1.94
Weighted sum*	**1.64**	**2.00**	**-0.74**	**0.38**	**-0.54**	**0.92**
2000-2006						
Petroleum refineries and other petroleum and coal products	-2.46	-4.77	2.17	0.14	-0.39	0.53
Asphalt paving, roofing and saturated materials	-1.65	-3.72	0.85	1.22	0.85	0.37
Weighted sum*	**-2.35**	**-4.62**	**1.98**	**0.29**	**-0.21**	**0.50**
Difference: 2000-2006 minus 1997-2000						
Petroleum refineries and other petroleum and coal products	-3.73	-6.36	2.48	0.15	0.35	-0.21
Asphalt paving, roofing and saturated materials	-5.35	-8.02	3.95	-1.28	0.29	-1.57
Weighted sum*	**-3.98**	**-6.62**	**2.72**	**-0.08**	**0.33**	**-0.41**

* The weights are the nominal output shares of the sub-industries at the beginning of each period, corresponding to those for the pure productivity growth effect in equation (A1) in Appendix A.

Table 11. The composition of oil production in Canada (%), 1985-2010

	Heavy	Light-medium	Sub total: conventional oil	Synthetic	Bitumen	Sub total: unconventional oil
1985	12.2	72.8	85.1	11.4	3.5	14.9
1986	12.6	68.5	81.1	12.6	6.3	18.9
1987	12.8	67.9	80.7	11.8	7.6	19.3
1988	13.0	66.5	79.5	12.5	8.1	20.5
1989	18.6	60.0	78.5	13.2	8.3	21.5
1990	20.2	57.6	77.8	13.4	8.7	22.2
1991	21.6	55.8	77.4	14.7	7.9	22.6

1992	23.8	53.5	77.3	14.8	7.9	22.7
1993	23.3	54.2	77.5	14.6	7.9	22.5
1994	23.7	53.6	77.3	15.0	7.7	22.7
1995	25.7	50.5	76.2	15.5	8.2	23.8
1996	28.1	47.8	75.9	15.2	8.9	24.1
1997	29.0	43.8	72.8	14.9	12.3	27.2
1998	27.0	43.8	70.8	15.3	14.0	29.2
1999	27.6	42.8	70.3	16.9	12.8	29.7
2000	28.0	41.6	69.6	16.0	14.4	30.4
2001	28.1	39.6	67.7	17.1	15.2	32.3
2002	25.3	40.8	66.1	20.1	13.8	33.9
2003	23.6	39.3	62.9	18.6	18.6	37.1
2004	22.8	35.9	58.7	19.1	22.2	41.3
2005	22.4	35.6	58.0	16.1	25.9	42.0
2006	20.9	33.4	54.3	20.0	25.7	45.7
2007	19.4	34.4	53.8	26.7	19.5	46.2
2008	18.2	34.6	52.9	25.6	21.5	47.1
2009	17.0	30.6	47.6	29.9	22.5	52.4
2010	15.6	29.5	45.1	28.8	26.1	54.9

Sources: Statistics Canada CANSIM table 126-0001

Note: Synthetic crude oil is high quality light crude oil derived from upgrading bitumen from oil sands; crude bitumen is heavy crude oil not recoverable commercially without application of in-situ recovery techniques for example steam injection.

Table 12. The composition of crude oils and equivalent feedstock (by type) for refinery processing in Canada (%), 1985-2010

	Heavy	Light-medium	Sub total: conventional oil	Synthetic	Bitumen	Condensate and pentanes plus	Sub total: un-conventional oil
1985	11.0	76.4	87.4	10.4	0.5	1.7	12.6
1986	10.8	75.7	86.6	11.4	0.3	1.7	13.4
1987	11.5	75.8	87.2	10.9	0.5	1.4	12.8
1988	10.1	77.1	87.2	10.7	0.4	1.7	12.8
1989	11.4	75.6	86.9	10.8	0.7	1.6	13.1
1990	12.6	74.6	87.1	10.6	0.5	1.8	12.9
1991	13.5	71.5	85.1	12.4	0.6	2.0	14.9
1992	15.3	69.2	84.4	12.4	0.9	2.2	15.6
1993	16.3	66.9	83.1	12.2	1.0	3.7	16.9
1994	17.8	65.0	82.8	14.0	0.8	2.5	17.2
1995	17.8	64.4	82.2	14.5	1.0	2.4	17.8

1996	18.5	62.7	81.1	15.0	2.1	1.8	18.9
1997	19.3	62.6	81.9	14.4	2.1	1.6	18.1
1998	20.8	61.0	81.8	13.8	2.2	2.2	18.2
1999	18.3	62.9	81.2	13.9	2.8	2.1	18.8
2000	19.5	62.7	82.1	12.5	3.1	2.3	17.9
2001	18.0	65.2	83.2	12.5	2.6	1.7	16.8
2002	13.1	69.4	82.5	12.7	3.3	1.5	17.5
2003	13.4	70.1	83.5	11.3	3.0	2.2	16.5
2004	13.8	66.1	79.9	14.3	3.4	2.3	20.1
2005	13.1	67.3	80.5	13.9	3.8	1.9	19.5
2006	14.1	64.9	79.0	15.1	4.3	1.7	21.0
2007	14.5	64.9	79.3	16.0	3.1	1.6	20.7
2008	12.9	66.6	79.5	16.4	2.8	1.3	20.5
2009	12.7	63.0	75.7	21.1	2.6	0.7	24.3
2010	14.0	62.5	76.5	21.4	1.7	0.3	23.5

Sources: Statistics Canada CANSIM Table 134-0001

Note: Condensate and pentanes plus is low density crude oil with a rating of over 40 degrees API, an internationally accepted measure of crude oil specific gravity.

Table 13. Regional shares of Canadian refinery output and domestic crude oil extraction

Petroleum refineries				
	1985	1995	2005	2010
Atlantic provinces	10.5	19.7	23.3	24.6
Quebec	20.3	21.2	23.3	21.9
Ontario	34.9	27.2	21.7	20.5
Alberta	21.2	23.5	23.9	24.6
Other provinces and territories	13.0	8.5	7.7	8.5
Crude Oils Extraction				
	1985	1995	2005	2010
Atlantic provinces, Quebec and Ontario*	0.1	1.5	13.1	10.2
Saskatchewan	13.5	17.8	17.8	15.5
Alberta	81.9	76.5	66.4	71.8
Other provinces and territories	4.4	4.2	2.7	2.5

Note: Quebec and Ontario have ineligible oil extraction industries so they are combined with Atlantic Provinces.
Sources: Statistics Canada CANSIM Tables 126-0001 and 134-0004.

Table 14. The composition of domestic and foreign refinery supply of crude oils and equivalent in Canada (%), 1985-2010

	Domestic	Foreign
1985	79.4	20.6
1986	73.7	26.3
1987	71.3	28.7

1988	69.7	30.3
1989	67.8	32.2
1990	65.5	34.5
1991	62.6	37.4
1992	63.4	36.6
1993	60.2	39.8
1994	59.7	40.3
1995	60.9	39.1
1996	57.1	42.9
1997	54.2	45.8
1998	53.2	46.8
1999	50.8	49.2
2000	47.3	52.7
2001	48.1	51.9
2002	50.7	49.3
2003	50.4	49.6
2004	51.0	49.0
2005	49.9	50.1
2006	52.3	47.7
2007	53.7	46.3
2008	52.4	47.6
2009	53.3	46.7
2010	56.1	43.9

Sources: Statistics Canada CANSIM table 134-0001.

Table 15. Input and output variety in the Canadian petroleum and coal manufacturing industries

Input variety index				
	1990	1995	2000	2003
Petroleum refineries	0.73	0.79	0.74	0.74
Asphalt paving mixture and block	0.43	0.34	0.32	0.27
Asphalt shingle and coating materials	X	X	X	X
Other petroleum and coal products	0.43	0.61	0.58	0.50
Output variety index				
	1990	1995	2000	2003
Petroleum refineries	0.20	0.24	0.28	0.26
Asphalt paving mixture and block	0.79	0.76	0.84	0.89
Asphalt shingle and coating materials	X	X	X	X
Other petroleum and coal products	0.69	0.76	0.71	0.59

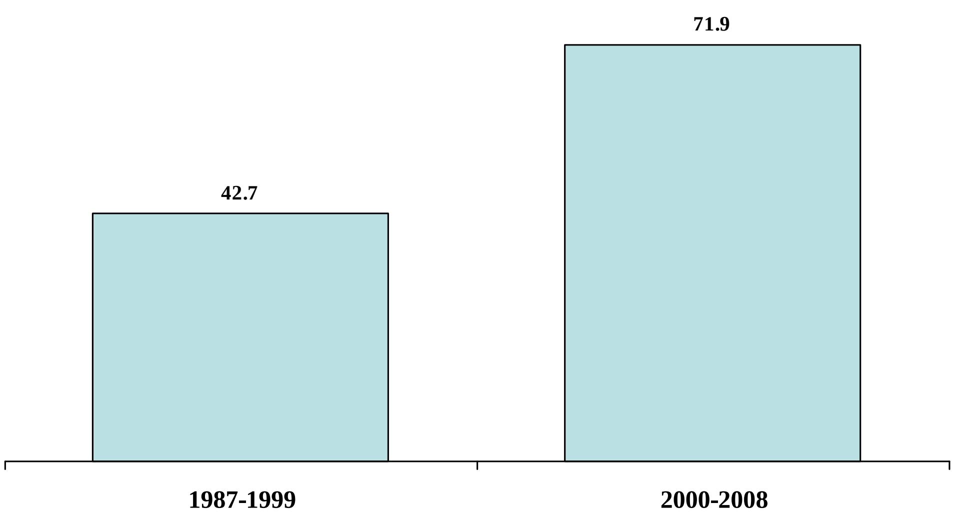
The cells with “X” are suppressed due to confidentiality concern.

Table 16. Regression results of input/output mix and their association with productivity

	(1)	(2)	(3)	(4)
Log (heat and energy expenditure)	0.320***	0.311***	0.325***	0.316***
	(0.022)	(0.022)	(0.022)	(0.022)
Foreign ownership dummy (base is domestic)	0.173***	0.138***	0.178***	0.142***
	(0.039)	(0.040)	(0.040)	(0.040)

Log (plant employment size relative to industry average) for petroleum refineries	0.000 (0.045)	0.014 (0.045)	0.000 (0.045)	0.018 (0.046)
Log (plant employment size relative to industry average) for asphalt paving mixture and block	-0.127*** (0.028)	-0.135*** (0.028)	-0.133*** (0.028)	-0.141*** (0.028)
Log (plant employment size relative to industry average for asphalt shingle and coating materials	0.047 (0.064)	0.060 (0.064)	0.044 (0.064)	0.059 (0.064)
Log (plant employment size relative to industry average) for other petroleum and coal products	-0.005 (0.035)	-0.002 (0.034)	-0.003 (0.035)	0.003 (0.035)
Synthetic crude input share for petroleum refineries		0.392*** (0.139)		0.393*** (0.139)
Other unconventional crude input share for petroleum refineries		-0.597*** (0.158)		-0.600*** (0.159)
Output diversity			-0.103 (0.065)	-0.073 (0.065)
Input diversity			0.077 (0.065)	0.101 (0.064)
Industry dummies	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes
Number of observations	1902	1902	1902	1902
Adjusted R-Square	0.39	0.40	0.39	0.40

Figure 1
Average Real Investment in Machinery and Equipment per Hour Worked*
in Canadian Petroleum and Coal Product Manufacturing
(U.S. Counterpart=100)



* Real investment in machinery and equipment (M&E) is in 2002 chained dollars, and the Canada-U.S. comparison is based on PPP for M&E in 2002 (Tang, et al. 2010)

Source: Author's calculation based on data from Statistics Canada, U.S. Bureau of Economic Analysis and U.S. Bureau of Labor Statistics

Endnotes

[1] Source: CANSIM table 383-0022.

[2] For comparison, the benchmarking value added in basic prices for Canada is adjusted to value added at factor cost. Similarly, for the U.S., value added in market prices is adjusted to value added at factor cost.

[3] Note that since the number of continuing plants relative to the number of entrants and exits can only decrease over time, the employment shares of entrants and exits should increase with time, assuming other factors being constant.

[4] The weighted sum of total components is similar but not identical to the pure productivity growth effect in the industry mix analysis, that is, the first term in equation (A1) in Appendix A. The discrepancy is due to a higher level of disaggregation of the petroleum and coal product industry for industry mix analysis than for plant turnover analysis.

[5] Bitumen makes up about 10 percent of the actual oil sands found in Alberta and the remainder is 80-85 percent sand, clay and silt and 4–6 percent water (Woynillowicz et al., 2005). The bitumen is separated from the thick, viscous mixture through fractional distillation and heating.

[6] The increased use of bitumen sands versus higher quality crude oil may also lead to more pollution and face stringent environmental regulations. Regulations can affect productivity directly when plants are forced to allocate inputs toward pollution abatement, or indirectly when firms with different productivities are affected differently by regulation, encouraging firm turnover or different levels of technology adoption. This paper makes no attempt to discuss regulation further since it is out of scope of this study.

[7] The under-investment may be largely explained by the fact that the demand growth for refined petroleum products in the matured North American market is expected to be weaker and that today's modern refineries are capital intensive, require sophisticated engineering, and typically have a replacement cost of over C$7 billion (the Conference Board of Canada, 2011).

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