Partial versus Total Factor Productivity: Assessing Resource Use in Natural Resource Industries in Canada

Alexander Murray
and Andrew Sharpe

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About Smart Prosperity Institute

Smart Prosperity Institute is a national research network and policy think tank based at the University of Ottawa. We deliver world-class research and work with public and private partners – all to advance practical policies and market solutions for a stronger, cleaner economy.

About the Centre for the Study of Living Standards

The Centre for the Study of Living Standards (CSLS) is a national, independent, not-for-profit economic research organization established in 1995. Its objectives are twofold. First, to contribute to a better understanding of trends and determinants of productivity, living standards and economic well-being through research. Second, to contribute to public debate by developing and advocating specific policies to improve the standard of living of Canadians.

About the Linking Natural Capital & Productivity project

The goal of this project is to shed light on the relationship between economic activity and the environment by exploring the linkages between changes in our natural capital and our measures of productivity generally, and through the construction of an environmentally adjusted measure of multifactor productivity specifically.

This paper seeks to complement the project's main focus on multifactor productivity with additional insights from partial productivity analysis of the natural resource sectors. As this paper argues, both multifactor productivity and partial productivity are informative, providing different insight that may be useful for different types of analysis, and both of which are required to gain a broad understanding of an industry's performance.

This project is a partnership of universities, governments and industry: Environment Canada, Natural Resources Canada, Industry Canada, the Forest Product Association of Canada, the University of Ottawa, Canadian academics at various universities, Sustainable Prosperity, the Organization for Economic Cooperation and Development, Shell, and the Centre for the Study of Living Standards. Thank you to the Social Sciences and Humanities Research Council of Canada for supporting this project. It is anticipated that additional partners will be added to the project over its lifespan.

A complete list of project references, sources and key terms can be found at http://nkp.smartprosperity.ca/partners

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Abstract

A *partial productivity* measure relates output to a single input. *Total factor productivity* (or TFP) relates an index of output to a composite index of all inputs. This report discusses the strengths and weaknesses of each type of productivity measure from theoretical and methodological perspectives. Different productivity measures may be useful for different analytical purposes, and no single measure provides a complete picture of an industry's productivity performance.

The report then presents estimates of TFP and a suite of partial productivity measures for a set of natural resource-related industries in Canada. The three forestry products industries and the crop and animal production industry exhibited the best productivity performance over the 1990-2012 period across a variety of productivity measures, while oil and gas extraction and mining experienced the worst productivity performance.

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Executive Summary

Productivity measures are often used to assess a country's economic performance. There are two types of productivity measure. A *partial productivity* measure relates output to a single input; examples include labour productivity (output per hour worked), capital productivity (output per unit of capital), and energy productivity (output per joule of energy used). *Total factor productivity* (or TFP) relates an index of output to a composite index of all inputs.

Conventional productivity metrics – whether partial measures or TFP – rarely reflect information about the usage of natural resources or the degradation of the natural environment due to pollution. The Smart Prosperity Institute is undertaking a project to produce productivity metrics for Canada that are adjusted to reflect these factors. This is an important project given the role of natural resources in Canada's economy. However, a shortcoming is that the Smart Prosperity Institute has focused on TFP alone.

The aim of this report is to argue for a balanced approach that incorporates partial productivity measures as well as TFP. The report discusses the strengths and weaknesses of each type of productivity measure from both theoretical and methodological perspectives. It then presents estimates of TFP and a suite of partial productivity measures for a set of natural resource-related industries in Canada. The point of this empirical material is to illustrate the range of productivity measures that can be examined using available data and to emphasize that TFP and partial productivity measures are complementary.

Strengths and Weaknesses of Productivity Measures

The usefulness of a productivity measure can be assessed along a number of dimensions:

- **Theoretical interpretation:** What are the correspondences between productivity measures and important concepts from economic theory?

- **Practical measurement issues:** How burdensome are the data requirements for various productivity measures? To what extent do the measures depend on methodological assumptions for which multiple reasonable choices exist?

- **Analytical or policy purpose:** What productivity measure is best suited for a particular analytical or policy purpose?

The bulk of this report is devoted to a discussion of TFP and partial productivity measures along these dimensions. Key points include the following:

- The main merit of TFP is its importance in economic growth theory.
    - Among economists, the dominant framework for thinking about economic growth is the neoclassical growth model pioneered by Nobel Prize-winning economist Robert Solow in the 1950s. In that framework, TFP growth is the ultimate source of long-run per-capita output growth.

  - The other key proximate source of growth – physical capital accumulation – is itself driven by TFP growth, according to the neoclassical view. Thus, TFP growth is the only fundamental source of economic growth.

- Outside of the simplest neoclassical framework, however, the interpretation of TFP becomes less clear. TFP has been described as "a measure of our ignorance"; it is a 'black box', the residual part of output growth that we cannot yet explain.
  - In addition to technological progress, TFP growth (as conventionally measured) captures the effects of factors such as factor utilization rates, imperfect competition in product markets, non-constant returns to scale, and changes in input quality.

- The common interpretation of TFP growth as a measure of technological progress is subject to several substantial caveats. In particular, TFP growth does not capture technological progress that is embodied in new capital equipment.

- Partial productivity measures are also of theoretical interest because of their close relationship to factor prices. This is especially true of labour productivity, which has a robust theoretical connection to wages and, hence, to living standards.

- For some purposes, a partial productivity measure may be more informative than TFP. Partial measures allow us to zero in on the efficiency of the use of specific resources that are of special interest in a particular context.
  - Energy productivity (i.e. output per unit of energy input used) may be more useful than TFP for measuring progress toward environmental policy goals.
  - Land productivity (i.e. output per unit of land input used) may be more useful than TFP for policymakers interested in agricultural policy or land management.
  - Given the tight connection between labour productivity and living standards, an environmentally-adjusted measure of labour productivity may be more useful than environmentally-adjusted TFP as a tool for assessing the effect of environmental damages on living standards.

- Careful TFP measurement requires a large amount of data – on output and on the quantities, prices and quality compositions of *all* inputs – and relies on methodological assumptions about which no expert consensus exists. Any given partial productivity measure requires less data and relies on fewer methodological assumptions. Challenges in productivity measurement include:
  - Unmeasured inputs (e.g. services provided for free by the natural environment)
  - Unpriced inputs (e.g. public infrastructure)
  - Methodological assumptions (e.g. how to measure the user cost of capital)

Productivity Trends in Canada's Natural Resource Industries

We present estimates of TFP growth and a set of partial productivity measures for primary and secondary natural resource industries in Canada. The primary industries are crop and animal production; forestry and logging; fishing, hunting and trapping; support activities for agriculture and forestry; oil and gas extraction; mining (except oil and gas); and support activities for mining and oil and gas extraction. The secondary industries are wood product manufacturing, paper manufacturing, and petroleum and coal product manufacturing.

For all productivity measures, we present estimates in which an industry's output is measured using gross output. For TFP and labour productivity, we also provide estimates based on value added.

Key results are as follows:

- There are significant differences across natural resource industries in terms of annual TFP growth.
  - Whether measured in terms of value added or gross output, the industries associated with the mining and oil and gas sector exhibited the worst TFP growth performance over the 1990-2012 period. The lowest TFP growth rate was in the oil and gas extraction industry, at -3.11 per cent per year on a value added basis or -2.09 per cent per year on a gross output basis.
  - By contrast, industries associated with the forestry industry (forestry and logging, paper manufacturing and wood products manufacturing) exhibited the best TFP growth performance over the 1990-2012 period.

- In both 1990 and 2012, the level of labour productivity (measured as real value added per hour worked) was far higher in the oil- and mining-related industries than in other industries. Labour productivity was highest in the oil and gas extraction industry in 2012, at $521.8 per hour (in chained 2007 dollars). The industry with the lowest level of labour productivity in 2012 was support activities for agriculture and forestry, at $29.7 per hour.

- On a value-added basis, labour productivity growth over the 1990-2012 period was highest in crop and animal production (4.17 per cent per year). Three industries exhibited negative labour productivity growth over the period: petroleum and coal products manufacturing (-1.28 per cent per year), oil and gas extraction (-1.17 per cent per year), and support activities for mining and oil and gas (-0.21 per cent per year).

- Capital productivity grew fastest in the paper manufacturing industry (3.49 per cent per year). Support activities for agriculture and forestry had the lowest capital productivity growth, at -2.96 per cent per year. The other industries that exhibited negative capital productivity growth over the period were those involved in the mining and oil and gas sector.

- Only three of the ten industries exhibited positive intermediate input productivity growth over the period: wood product manufacturing (0.30 per cent per year), forestry and logging (0.17 per cent per year) and paper manufacturing (0.06 per cent per year). The largest decline in intermediate input productivity was in oil and gas extraction, at -2.51 per cent per year.

- The productivity measure with the largest variance in growth across industries by far was water productivity. Four of the eight industries for which data are available enjoyed reductions in water usage per unit of gross output. Wood product manufacturing exhibited massive improvements in water productivity (22.1 per cent per year) while support activities for mining and oil and gas extraction had a massive deterioration (-17.6 per cent).

- Paper manufacturing exhibited the fastest rate of energy productivity growth over the 1990-2012 period, at 2.38 per cent per year. The industries associated with the oil and gas sector also exhibited positive energy productivity growth. The largest decline in energy productivity was in fishing, hunting and trapping (-2.18 per cent per year).

- Greenhouse gas intensity increased in two industries: support activities for agriculture and forestry, at 3.56 per cent per year, and mining (except oil and gas), at 1.10 per cent per year. All other industries experienced negative greenhouse gas intensity growth over the period (i.e. their production processes became cleaner on a per-unit basis), including the oil and gas industry and the petroleum and coal products manufacturing industry

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I. Introduction[1]

The exploitation of natural resources is a key driver of Canada's economic performance. Canada is endowed with one of the richest resource bases of any country in the world; it ranks third in the world by endowment of forested area, renewable freshwater resources and oil reserves, and seventh by endowment of arable land (Sustainable Prosperity, 2014). This stock of natural capital is an important input into production in Canada, with the mining, forestry and energy industries accounting ("directly and indirectly") for almost 20 per cent of Canada's GDP in 2013 (Sustainable Prosperity, 2015).

Productivity measures are often used to assess a country's economic performance. In spite of the importance of natural capital in Canada, however, productivity metrics rarely reflect information about the usage of natural capital or the degradation of the natural environment as a byproduct of production processes. The exclusion of natural capital from productivity measures may lead to the mismeasurement of productivity levels and growth rates (although the direction of the error is unknowable *a priori*). To remedy this problem, the Smart Prosperity Institute is undertaking a project to produce productivity metrics for Canada that are adjusted to reflect natural capital inputs and pollution outputs.

As Sustainable Prosperity (2015) points out, there are two types of productivity measure. A *partial productivity* measure relates output to a single input; examples include labour productivity (output per hour worked), capital productivity (output per unit of capital), and energy productivity (output per joule of energy used). *Total factor productivity* (or TFP) relates an index of output to a composite index of all inputs.[2] Although it acknowledges that both partial productivity measures and TFP are important metrics and that the analytical value of each is maximized by analyzing them both together, the Smart Prosperity Institute focuses solely on TFP in its work.

The aim of this report is to argue for a balanced approach that incorporates partial productivity measures as well as TFP. In Section II, we provide technical definitions of TFP and partial productivity and outline the relationship between them. We then discuss the strengths and weaknesses of each type of productivity measure from both a theoretical perspective and a methodological perspective. In Section III, we present estimates of TFP and a suite of partial productivity measures for a set of natural resource-related industries in Canada. The purpose of that section is to emphasize that TFP and partial productivity measures are complementary. Neither type of productivity measure, by itself, provides a complete picture of productivity trends; a complete understanding of productivity growth is best achieved by examining TFP and partial productivity measures together. Section IV contains concluding remarks.

II. Partial versus Total Factor Productivity: Conceptual Issues

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[1] This report was written by Alexander Murray, an economist at the Centre for the Study of Living Standards (CSLS) and CSLS Executive Director Andrew Sharpe. The authors thank Nicholas Oulton, Bert Waslander, and officials from Natural Resources Canada and the Forest Products Association of Canada for comments, and Michelle Brownlee from the Smart Prosperity Institute for the invitation to prepare this report.
E-mail: alexander.murray@csls.ca; andrew.sharpe@csls.ca

[2] Total factor productivity (TFP) is sometimes called multifactor productivity (MFP). Statistics Canada's productivity accounts use the term MFP, while TFP is more common in the academic literature. Throughout this paper, we will always use TFP.

In this section, we define total factor productivity and partial productivity and explain the relationship between them. We then discuss the strengths and weaknesses of each type of productivity measure. The discussion is conceptual rather than empirical, but empirical evidence is referred to when it helps to illustrate a conceptual point.

A. Definitions of Partial and Total Factor Productivity, and the Relationship Between Them

A firm uses inputs to produce output.[3] Intuitively, the ratio of the firm's output to its input defines its *productivity*; a firm that produces more output per unit of input is more productive. But how should 'units of input' be measured, given that there are many types of input and each is measured in different units (hours of work, hectares of land, barrels of oil, and so on)? Different choices of input correspond to different definitions of productivity.

Let us be precise. Let $X_{1,t}, \dots, X_{N,t}$ denote the real volumes of the N inputs used by the firm at date t, and let Q_t be the firm's real output. One way of assessing the firm's productivity growth between dates $t-1$ and t is to compare the growth of Q_t to that of each of the N inputs one at a time. Let $A_{i,t} = \frac{Q_t}{X_{i,t}}$ be the partial productivity of input i. Then the *partial productivity growth* of input i at time t is

$$\Delta \ln A_{i,t} = \Delta \ln Q_t - \Delta \ln X_{i,t}$$

where $\Delta \ln Q_t = \ln Q_t - \ln Q_{t-1}$ and so on. Positive partial productivity growth for input i indicates that the firm is able to produce more output per unit of input i it uses. The most common partial productivity measure is labour productivity, which is obtained when $X_{i,t}$ corresponds to the number of hours of labour used by the firm during period t. $\Delta \ln A_{i,t}$ then corresponds to growth in the firm's output per hour of labour input. In general, partial productivity can be computed for any input.

Each partial productivity measure provides an incomplete picture of the productivity with which the firm uses its inputs, and to keep track of the firm's partial productivity growth for all N inputs may be cumbersome. We may desire a single index of change in the productivity with which the firm uses all its inputs together. A reasonable way to combine the growth rates of the N inputs $X_{1,t}, \dots, X_{N,t}$ into a single composite input growth rate $\Delta \ln X_t$ is to use the following index:

$$\Delta \ln X_t = \sum_{i=1}^{N} \omega_{i,t} \Delta \ln X_{i,t}$$

where the weight $\omega_{i,t}$ is the average share of input i in total input costs in periods $t-1$ and t.[4] Then the firm's *total factor productivity growth* is defined as

$$\Delta \ln A_t = \Delta \ln Q_t - \Delta \ln X_t$$

Total factor productivity (TFP) growth measures changes in the amount of output the firm produces from given quantities of its full set of inputs, not just one input.

[3] We will discuss productivity in terms of a firm, but in general the production unit could be an industry, a province, a country, etc.
[4]This formula is called a Tornqvist index. The reasonableness of this approach can be defended on the grounds that the Tornqvist index is a discrete-time approximation of the ideal continuous-time index that can be derived from a production function under the assumption that an input's price is equal to its marginal product. See Hulten (2001) for a comprehensive discussion. In practice, Statistics Canada constructs volume and price measures using a different method, the chained Fisher index. It can be shown that the numerical discrepancy between Fisher and Tornqvist indexes is small.

There is a well-known relationship between the firm's TFP growth rate and its partial productivity growth rates. It is usually the case that $\sum_{i=1}^{N} \omega_{i,t} = 1$.[5] If this is true, then the expressions above can be combined to yield

$$\Delta \ln A_t = \sum_{i=1}^{N} \omega_{i,t}(\Delta \ln Q_t - \Delta \ln X_{i,t}) = \sum_{i=1}^{N} \omega_{i,t} \Delta \ln A_{i,t}$$

Thus, TFP growth is the weighted sum of the partial productivity growth rates for all the inputs, where the weights are the inputs' cost-share weights.

The expressions for TFP growth, partial productivity growth, and the relationship between them yield several insights about the various productivity measures. First, the data requirements for TFP measurement are burdensome relative to the data requirements for a given partial productivity measure. Measurement of TFP growth requires time series measures of real output, *all* of the real inputs used by the firm, and the nominal cost shares necessary to compute the weights. The need for data on all inputs can pose a problem if the firm uses some inputs that are unobserved or non-marketed. Second, the fact that the composite input X_t is a unit-free growth index implies that TFP can be measured only in growth rates; we do not have a meaningful measure of the absolute level of TFP.[6] Third, the complexity of TFP may make it difficult to explain to non-experts. By contrast, a partial productivity measure is relatively easy to compute and to explain to non-experts, and it can be measured in both levels and growth rates.

In addition to posing different practical challenges for measurement, TFP and partial productivity measures have different connections to economic theory. These points and others are discussed in the remainder of this section, which outlines the strengths and weaknesses of partial productivity measures and TFP.

B. Strengths and Weaknesses of the Productivity Measures

i) Theoretical Considerations

TFP in economic theory

An analyst's choices about what to measure are guided by the implications of theory about what it is important to measure. The main merit of TFP is its importance in economic growth theory. Among economists, the dominant framework for thinking about economic growth is the neoclassical growth model pioneered by Solow (1956; 1957). In that framework, TFP growth is the ultimate source of long-run economic growth.

Suppose the relationship between the firm's output Q_t and its N inputs is described by the production function

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[5]In theory, the weights sum to one if the firm's production function exhibits constant returns to scale (and input prices equal marginal products, as has already been assumed). The sum of the weights would exceed one under increasing returns to scale. In practice, the input cost shares are almost always constructed in a way that implies that they sum to one.

[6] It is possible to measure the *relative* TFP levels of two firms (or industries, countries, etc.). Essentially, this can be done by using the above formulas but measuring the log-differences as differences between firms at a point in time rather than changes within a firm over time. We do not pursue this issue further here. See Uguccioni (2016b) for an example of relative TFP level measurement in the context of the Canadian railway industry.

$$Q_t = F(X_{1,t}, \ldots, X_{N,t};\ A_t)$$

Output depends on the input quantities $X_{1,t}, \ldots, X_{N,t}$, which are controlled by the firm, and on a scaling factor A_t that the firm takes as given. When A_t increases, the firm can produce more output for any given amount of inputs. Taking the total logarithmic differential of this function, and assuming that markets are competitive, we obtain

$$\frac{\dot{A}_t}{A_t} = \frac{\dot{Q}_t}{Q_t} - \sum_{i=1}^{N} \omega_{i,t} \frac{\dot{X}_{i,t}}{X_{i,t}}$$

where $\frac{\dot{A}_t}{A_t}$, $\frac{\dot{Q}_t}{Q_t}$ and $\frac{\dot{X}_{i,t}}{X_{i,t}}$ denote the growth rates of A_t, Q_t and $X_{i,t}$, respectively, and $\omega_{i,t}$ is the cost share of input i as defined earlier.[7] If we use log differences as discrete-time approximations of the growth rates in this equation, we obtain the index number for TFP growth, $\Delta \ln A_t$, given in the previous subsection. Thus, the empirical TFP measure corresponds to the production function scale term in neoclassical growth theory.

Why are economists so interested in measuring the production function scale term A_t? Because in neoclassical growth theory, growth of A_t is the fundamental determinant of all per capita output growth. Hulten (1978) shows that, within this framework, aggregate TFP growth is interpretable as an outward shift in the economy's production possibilities frontier. Basu *et al.* (2013b) argue that the growth rates of TFP and of the per-capita capital stock provide, to a first order of approximation, a complete summary of changes in consumer welfare irrespective of the form of the production technology or the degree of competitiveness of product markets.

Within this framework, growth of partial productivity measures is driven by TFP growth in the long run. It is common to use the neoclassical growth accounting framework to decompose the partial productivity measure for one input into two proximate sources: TFP growth and factor deepening (that is, increases in the quantity of other inputs relative to the one input for which the productivity measure is being measured). An analyst who is firmly committed to the neoclassical theory, however, would claim that TFP growth is the only source of growth; if TFP growth were to cease, then factor deepening would eventually stop as well. The implications of this point for assessing the 'importance' of TFP growth are discussed by Hulten (1979).

For concreteness, consider a two-input model with $Q_t = A_t F(K_t, L_t)$, where K_t is physical capital and L_t is labour. Using the accounting relationships discussed earlier, it can be shown that the growth rate of the partial productivity of labour may be expressed as

$$\Delta \ln A_{L,t} = \Delta \ln A_t + \omega_{K,t} \Delta \ln \left(\frac{K_t}{L_t}\right)$$

The two proximate causes of labour productivity growth are TFP growth, $\Delta \ln A_t$, and capital deepening, $\Delta \ln \left(\frac{K_t}{L_t}\right)$. But the neoclassical theory implies that the cessation of TFP growth would lead, in the long run, to the end of per-

[7] For readers interested in the mathematical details: the total logarithmic differential of the production function is

$$\frac{\dot{Q}_t}{Q_t} = \sum_{i=1}^{N} \frac{\partial F(\cdot)}{\partial X_{i,t}} \frac{X_{i,t}}{Q_t} \frac{\dot{X}_{i,t}}{X_{i,t}} + \frac{\dot{A}_t}{A_t}$$

where a dot above a variable denotes the derivative of that variable with respect to time. (The units of A_t are arbitrary, so we are free to normalize the elasticity $\frac{\partial F(\cdot)}{\partial A_t} \frac{A_t}{Q_t}$ to one.) If markets are competitive, the profit-maximizing firm chooses its inputs so that the output elasticity $\frac{\partial F(\cdot)}{\partial X_{i,t}} \frac{X_{i,t}}{Q_t}$ is equal to the firm's expenditure on input i as a share of nominal output. Earlier, we denoted these shares by $\omega_{i,t}$. Rearranging the equation for $\frac{\dot{A}_t}{A_t}$ then yields the expression given in the main text.

worker capital accumulation and, hence, to the end of growth in the partial productivity of labour.[8] Thus, in a fundamental sense, it is incorrect to attribute any part of labour productivity growth to capital deepening. Capital deepening is a proximate source of labour productivity growth, but TFP growth is the only fundamental source.

The preceding discussion presents the traditional theoretical argument for focusing on TFP growth as the most important notion of productivity growth. It explains why TFP has interested economists from a theoretical perspective and why economists have been motivated to measure TFP in spite of many practical challenges. Before moving on to a detailed discussion of practical issues in productivity measurement, there remain five theory-based points worth noting.

Theory-dependent interpretation

The first is that the central role of TFP in economic growth is theory-dependent. Exogenous growth in the production function scaling factor is the ultimate source of long-run growth in the basic neoclassical model. But in practice, few economists believe that the neoclassical theory provides a satisfying account of real-world economic growth. It has been acknowledged from the beginning that TFP is "a measure of our ignorance"; it is a 'black box', the residual part of output growth that we cannot yet explain (Abramovitz, 1956). Considerable subsequent research effort has aimed to explain it by building theories in which TFP growth is the endogenous result of actions taken by decision-makers.

In the endogenous growth model of Romer (1986), for example, the production function exhibits constant returns to scale in capital and labour from the perspective of an individual firm but increasing returns in the aggregate because capital accumulation produces positive externalities that firms do not take into account in their decisions.[9] One could still compute the TFP index for this economy, but it would capture the spillover effect from capital rather than (or in addition to) the growth of an exogenous production function shifter. The fundamental determinant of long-run growth is no longer exogenous TFP growth, as it is in the neoclassical model, but rather the set of parameters that govern capital investment behaviour and the positive externalities. Since TFP growth now follows capital accumulation rather than driving it, it is no longer a more fundamental measure of productivity than partial productivity measures (Sargent and Rodriguez, 2000).[10]

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[8] Under the usual assumption that the marginal product of capital declines as the capital stock rises (everything else being equal), investors accumulate capital up to the point at which the value of the marginal product of capital is equal to the marginal cost. With no TFP growth, capital accumulation would stop here. TFP growth raises the marginal product of capital at any given level of the capital stock, and thereby provides investors with an incentive to continue accumulating capital.

[9] Here, 'capital' should be taken to include not only machines and buildings but also the stock of 'knowledge capital' that arises from R&D. The positive externality reflects the spillover of ideas across firms.

[10] Using data from a set of OECD countries, Oulton (2016) poses the following question: By how much would the elasticity of aggregate output with respect to aggregate capital have to exceed the capital share of output (i.e. the capital elasticity of output faced by a firm that ignores spillovers) in order for capital spillovers to fully explain measured TFP growth? He finds that in most countries, the elasticity would have to be more than twice as large as the observed capital share. He finds it implausible that spillover effects could be that large, and therefore concludes that capital spillovers alone cannot explain all of measured TFP growth. See Romer (1987) for a related analysis.

Sensitivity to assumptions

The second point is that, even within the neoclassical paradigm, the interpretation of A_t is sensitive to many assumptions including, but not limited to, assumptions about the competitiveness of markets, the rate of factor utilization, returns to scale in the production function, changes in the quality of inputs, and the manner in which technological change augments different factors of production. If factor or product markets are not competitive, if firms vary factor utilization rates over time in response to business conditions, if the production function does not exhibit constant returns to scale, if input quality changes are unmeasured, or if technological improvements augment the marginal products of different factors differently, then the identification of the TFP index with a production function scaling factor breaks down.[11] Hulten (2001) provides a simple example in which capital and labour are augmented by separate exogenous scale factors. In this case, he shows that the usual TFP measure captures not only the growth rates of these scale factors but also changes in the factor cost shares.

TFP growth is not a measure of technological change

The third point is that, even leaving aside its sensitivity to assumptions, the interpretation of TFP as a measure of technical change is subtle. TFP growth is commonly equated with technological progress, but this is inappropriate. As Gordon (2016, pp. 569) emphasizes, "innovation is the ultimate source of all growth in output per worker-hour, not just the residual after capital investment is subtracted out." Many technological improvements are embedded in new forms of machinery and equipment, and firms adopt them by substituting these new types of capital for other inputs. This 'embodied' technical change is not captured in TFP (Jorgenson and Stiroh, 1999). Moreover, even disembodied innovations (improved management practices, for example) that arise from R&D expenditures should, to the extent that the returns are captured by the investors, be included in the output and input payments of the firms that conduct the R&D. TFP grows only to the extent that the benefits of the innovation spill over to firms that did not pay for it; that is, TFP reflects only the costless component of technological change (Jorgenson and Griliches, 1967). Lipsey and Carlaw (2004) reiterate this point and show how the timing of technology diffusion and the associated output changes affect the way in which technical progress shows up in TFP indexes. Thus, the interpretation of TFP as a measure of technical progress is subject to significant caveats even if all the assumptions underlying its measurement are true.[12]

Partial productivity measures and factor prices

The fourth point is that partial productivity measures are also of theoretical interest because of their close relationship to factor prices. This is especially true of labour productivity, which has a robust theoretical connection to wages and, hence, to living standards. As noted earlier, the competitive firm will hire labour until the output elasticity of labour

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[11] Much of the cutting-edge research on TFP measurement focuses on disentangling these factors and isolating the technology growth component. Basu *et al.* (2006) construct a 'purified' measure of annual U.S. TFP growth that accounts for imperfect competition, variable factor utilization, input quality and non-constant returns to scale. Basu *et al.* (2013a) update the method and estimate measures of TFP growth for the consumption and investment goods sectors. Fernald (2014) provides estimates of consumption sector, investment sector, and total business sector TFP growth at a quarterly frequency, adjusted for input quality and variable factor utilization but not for non-constant returns to scale or imperfect competition (due to limitations in the availability of quarterly data). These studies attempt to strip out the factors that contaminate the usual TFP index and recover measures of the production function scale factor. The data requirements are extremely burdensome; detailed industry-level and worker-level data are needed. Moreover, additional behavioural assumptions are required in order to measure unobserved factors such as input utilization rates.

[12] This may in part explain the perplexing fact that Statistics Canada's official measure of TFP (which the agency calls multifactor productivity, or MFP) has exhibited zero cumulative growth since the late 1970s in spite of the obvious fact that a substantial amount of technological change has occurred since then. The Statistics Canada MFP index for the business sector was 98.2 in 1978 and 98.3 in 2013 (from CANSIM Table 383-0021). Another part of the explanation may be measurement challenges.

and the nominal output share of labour costs are equal.[13] Letting β_t denote the output elasticity of labour and w_t the real wage, this implies

$$w_t = \beta_t A_{L,t}$$

Thus, the average real wage is proportional to the partial productivity of labour, $A_{L,t}$. In the most common framework with Cobb-Douglas technology, β_t is constant over time so that the average real wage is proportional to labour productivity. This relationship (or something close to it) holds even in many models in which the TFP residual is hard to interpret. Theory therefore provides us with a reason to care about labour productivity (or partial productivity measures more generally) as well as TFP.

Interpreting partial productivity measures

The final point is that partial productivity measures are not without their own problems in terms of interpretation. In the neoclassical growth model, for example, the capital-labour ratio grows at the same rate as labour productivity in the long run − which implies that capital productivity growth in the long run is zero. A naive analyst who observes rising labour productivity and constant capital productivity might conclude that there is some problem with the way the economy is using capital, but this would be incorrect; constant capital productivity would simply reflect the continuous accumulation of new capital at the optimal rate. More generally, growth of the partial productivity of a given input may reflect factors that have little to do with that input. For example, labour productivity may rise not because workers are working harder or becoming more skilled, but simply because they have more capital to work with.

Simple models provide frameworks for organizing and interpreting data, but empirical evidence is often at odds with the models that have been referred to in this section. One example is that, in Canada and across the OECD, the growth paths of average wages and labour productivity have diverged significantly in recent decades, with wages growing more slowly than labour productivity (Sharpe *et al.*, 2008; Uguccioni, 2016a; and Uguccioni and Sharpe, 2016). A second example is that the basic neoclassical model implies that TFP growth drives capital deepening, but Oulton (2016) finds no evidence of this in OECD data. In fact, he finds that higher TFP growth leads to *lower* subsequent capital accumulation.

Such theoretical puzzles may lead us to give more weight to practical considerations when deciding on the relative prominence of different productivity measures.

ii) Practical Considerations

In practice, the choice of productivity measure should reflect the objectives of the analyst. For some purposes, a partial productivity measure may be more informative than TFP. This is especially true in the realm of environmental policy and sustainability. Energy productivity (i.e. output per unit of energy input used) may be more useful than TFP for measuring progress toward environmental policy goals, for example. For policymakers interested in agricultural policy or land management issues, a measure of land productivity (i.e. output per unit of land input used) may be more useful than TFP. Given the tight connection between labour productivity and living standards, an environmentally-adjusted measure of labour productivity may be more useful than environmentally-adjusted TFP as a tool for assessing the effect of environmental damages on living standards. The general point is that partial measures allow us to zero in on the efficiency of the use of specific resources that are of special interest in a particular context.

[13] This is equivalent to the condition that marginal revenue equals marginal cost.

In cases in which a partial productivity measure is preferable to TFP, an important side-benefit is that partial measures are (individually) easier to construct than TFP.[14] Careful TFP measurement requires a large amount of data – data on output and on the quantities, prices and quality compositions of *all* inputs. Diewert (2000) identifies at least nine types of input that must be measured: labour; intermediate inputs; reproducible capital; inventories; land; natural resources; working capital, money, and other financial instruments; knowledge capital; and infrastructure. The measurement of some of these elements is itself sensitive to modelling assumptions; analysts who possess the same raw data but who make different – and arguably equally defensible – methodological choices can end up with markedly different TFP estimates. In addition, the fact that the composite input measure is a unit-free growth index implies that TFP can be measured only in growth rates; we have no meaningful measure of the absolute level of TFP. By contrast, a partial productivity measure carries less burdensome data requirements, is less sensitive to controversial assumptions, and can be measured in both levels and growth rates.

The remainder of this section reviews some of the measurement challenges that arise in measuring TFP growth. Each of these challenges would also impinge on the measurement of a particular partial productivity measure; for example, difficulties in measuring capital services pose a problem for the measurement of capital productivity. But challenges associated with one input do not spill over to the measurement of partial productivity for other inputs. For TFP, by contrast, all the challenges matter.

Unmeasured and unpriced inputs

The fact that TFP measurement requires data on the volumes and cost shares of all inputs immediately raises two distinct but related challenges. The first is the problem of unmeasured inputs. The second is the problem of unpriced (or non-marketed) inputs.[15]

A firm's production process may depend on inputs that statistical offices do not measure. Intangible capital has been an important example of this, although official statistical offices are improving along this dimension.[16] For another example, consider the role of bees (and the ecosystem that supports them) in the agriculture sector. Official statistical offices do not produce measures of the pollination services of bees or other services provided by the natural environment that are used as inputs in agricultural production. The exclusion of these services from measured inputs means that TFP growth measures will be distorted; the part of output attributable to those unmeasured services will be attributed (incorrectly) either to other inputs or to 'technology.' The size of the distortion depends on the output

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[14] Of course, to estimate the entire set of partial productivity measures would require most of the same data that are needed for TFP measurement. As noted above, however, researchers and policymakers often require only one partial productivity measure in order to do their work.

[15] Conventional inputs, such as labour and machinery and equipment, are both measured and priced. Public infrastructure (roads, bridges, etc.) is an example of an input that is measured but usually not priced; we have measures of infrastructure, but for the most part firms do not pay a market price for the services of infrastructure. (There are sometimes fees, such as tolls or congestion taxes for the use of roads.) The services of the natural environment (e.g. the pollination services of wild bees or the water supplied by rain) constitute an example of unmeasured, unpriced inputs. We can think of no examples of inputs that are priced but unmeasured; the national accounts can in principle capture all inputs that are bought and sold on markets.

[16] Intangible capital is also called knowledge-based capital or intellectual property products. According to the 2008 System of National Accounts (SNA) definition, it includes five types of asset: research and development; mineral exploration and evaluation; computer software and databases; entertainment, literary and artistic originals; and other intellectual property products (Ahmad and Schreyer, 2016). Corrado *et al.* (2005) identify a number of additional types of intangible capital, including branding and advertising, financial innovation, and innovations in organizational structure. Statistical offices differ in their treatment of the components of intangible capital. Software has long been counted in nonresidential investment, but the U.S. Bureau of Economic Analysis only began treating R&D as a form of capital investment in 2013, in response to the 2008 SNA revisions; until then, it had been treated as an intermediate input expenditure (Bureau of Economic Analysis, 2013). At Statistics Canada, research on the measurement of intangible capital and on its inclusion in the growth accounting framework is ongoing (Baldwin *et al.*, 2009; 2012).

elasticity of the excluded input (which determines the weight it should receive in TFP calculations) and on the extent to which the growth rate of the excluded input differs from that of the composite index of included ones.

How do unmeasured inputs affect partial productivity measures? Clearly a partial productivity measure cannot be computed for an input that is not measured. However, the absence of data on one input does not distort the measurement of the partial productivity of any other input.

The problem of unpriced inputs arises when an input has no market price. Consider the example of infrastructure such as roads and bridges. Such assets are measured as part of the stock of reproducible capital if privately owned, but much of the stock of infrastructure is publicly owned. The transportation services provided by public roads are a valuable input for firms, but firms do not pay a market price for those services. (They may sometimes pay fees, such as tolls or licensing fees.) Such prices are required in order to compute the cost-share weight on infrastructure in the composite input growth index for TFP measurement, so the fact that there is no market for infrastructure services poses a challenge. It is possible to develop econometric estimates of unobserved 'shadow prices,' but such estimates are sensitive to the methodological assumptions underlying them.

Sensitivity to methodological assumptions

The sensitivity of estimates to controversial methodological assumptions is a problem that extends to the measurement of other capital assets. We consider two examples. The first is the measurement of intangible capital, and the second is the measurement of physical capital services.

Consider the example of knowledge capital, a component of intangible capital. Two prices are required in order to include knowledge capital in a TFP measure: the price of R&D investment and the user cost of knowledge capital. The former is used to deflate nominal R&D expenditures into an index of real R&D investment, while the latter is used to construct the cost share weight on knowledge capital in a composite input index. TFP measurements will be sensitive to the methodological choices made by the analyst, and different choices may be defensible.

Corrado *et al.* (2005) deflated intangible capital investment by the non-farm business sector GDP deflator, while Bureau of Economic Analysis (2007) used the output deflators of R&D-intensive industries. Alternatively, prices could be estimated based on the costs of the inputs (mainly labour and materials) that were used to produce the intangible assets. In their experimental estimates of intangible capital in Canada, Baldwin *et al.* (2012) use asset-specific deflators for some components of intangible capital and follow the approach of Corrado *et al.* (2005) otherwise. User cost estimates depend on these investment prices as well as estimates of depreciation rates, relevant tax rates, and the opportunity cost of capital.

Controversial measurement assumptions also affect the measurement of capital services. Diewert and Yu (2012) estimate that TFP in the Canadian business sector grew by 1.03 per cent per year over the 1961-2011 period. Statistics Canada's official estimates suggest that TFP growth over that period was 0.28 per cent per year. Gu (2012) attributes this difference to the fact that Diewert and Yu's estimate of the growth rate of capital services – at 3.0 per cent per year – is far lower than the official Statistics Canada estimate of 4.8 per cent per year. Faster measured growth of capital input, everything else being equal, implies slower measured growth of TFP. Gu traces the discrepancy in the capital services growth estimates to three main methodological differences:

- Statistics Canada estimates capital services at the industry level and then aggregates them to a business-sector estimate. Diewert and Yu compute capital services directly at the business sector level.

- In estimating the user cost of capital, Statistics Canada assumes that competitive forces equalize the *nominal* rate of return across assets and that the user cost includes asset-specific capital gains. Diewert and Yu assume that the *real* rate of return is equalized across assets and that the user cost does not include asset-specific capital gains.

- Statistics Canada uses more detailed data on capital assets than do Diewert and Yu.

A detailed discussion of these methodological differences is beyond the scope of this report.[17] The point is that there is no expert consensus that either set of assumptions is 'better' or 'worse' than the other, yet the choice matters enormously for the measurement results. Schreyer (2012) notes that the part of the TFP growth discrepancy attributable to the first bullet point in the list (i.e. the choice of a top-down versus a bottom-up approach) is interpretable as an industry reallocation effect; whether one wishes to include that effect in a TFP measure depends on one's purposes. He also points out that "although user costs of capital are officially recognized in the System of National Accounts, there is no single recommendation on the details of implementation." Thus, TFP estimates can vary substantially based on the methodological preferences of the analyst constructing them.

A partial productivity measure, by contrast, depends only on a measure of output and a measure of one input. While capital productivity is affected by the challenges associated with measuring capital services, the partial productivity of other inputs is unaffected. In particular, labour productivity – the most common partial productivity measure – does not require the measurement of capital services. Labour input is easy to measure compared to capital services. This is especially true if we do not care about separating the effect of labour quality growth from other sources of labour productivity growth. In that case, we need only count aggregate hours worked as a measure of labour input.

Transparency

TFP carries burdensome data requirements, relies on complex methodological judgments about which experts disagree, and has a subtle interpretation that differs from common notions of 'technical progress.' An implication of these observations is that TFP measures lack transparency and are difficult for non-experts to understand. Partial productivity measures are easier for the public to understand and relate to. Anyone can grasp the sense in which a firm has grown more productive if it produces more output per hour worked, for example. It is more difficult to explain to non-experts why they should care whether output growth exceeds a cost-share weighted average of the growth rates of input volume indexes. This is an important consideration when it comes to communicating with the public about economic policies aimed at promoting productivity growth.

Challenges affecting both TFP and partial productivity measures

Finally, it is worth pointing out two measurement challenges that affect both TFP and partial productivity measures. The first is the challenge of measuring output quality changes. The second is the issue of the comprehensiveness of the output measure, especially with respect to externalities like pollution.

Output quality is said to have improved if the same physical volume of output delivers more satisfaction to consumers than it had in the past, everything else being equal.[18] Many technological changes take the form of output quality

[17] Gu (2012) contains such a discussion.

[18] We focus on the production of consumer goods in this discussion. Aggregate output includes both consumption and capital goods. The latter are both outputs and inputs of production, so the effects of quality change in capital goods on productivity measures are subtle. An improvement in capital goods quality raises effective inputs but also raises output, and the effects on productivity are offsetting. Along the optimal growth path, the effects cancel exactly. See Hulten (2001) and the references therein.

improvements. Arguably, these improvements (or at least the costless portion of them) should be included in productivity measures, but they will not be if the output measure is not adjusted to account for quality change. If the quality of a firm's output doubles but it still produces the same physical volume of output using the same physical quantities of inputs as before, productivity measures based on price or output measures that are not quality-adjusted will register no change even though consumers are better off. If the same welfare improvement had been achieved by doubling the physical volume of output produced with the given inputs, measured productivity would have doubled.

In order for productivity measures to capture quality change, real output must be measured in 'efficiency units' that include both physical volume and quality change. Discussions of the econometric methods that can be used to develop such estimates and the quantitative importance of unmeasured quality change for productivity measures are beyond the scope of this report.[19] In practice, statistical offices do not measure output in quality-adjusted terms except for certain goods and services (e.g. computers) for which quality change is believed to be of particular importance.[20]

The comprehensiveness of an output measure refers to its scope in terms of what is counted as output and what is not. A comprehensiveness issue of particular importance is the measurement of negative environmental externalities from production – greenhouse gases and other pollutants.[21] The level of a productivity measure may be overstated if the costs of pollution are not valued (negatively) as a part of output. The growth rate of a productivity measure may be understated (overstated) if the pollution component of output is declining (rising) over time.

iii) Summary

The discussion in this section has stressed challenges associated with measuring and interpreting TFP. It has pointed out that partial productivity measures are often simpler to compute and easier for non-experts to interpret, and that they can provide targeted insights that a measure like TFP, based on an index of multiple inputs, misses. On the other hand, any given partial productivity measure necessarily provides an incomplete picture of overall productivity performance. Attempting to examine every partial productivity measure could lead to 'information overload,' and a single summary indicator such as TFP can be useful. Our point is not that one type of productivity measure is always and everywhere superior to the other. Both types of measure are useful in certain analytical contexts.

The next section illustrates the usefulness of partial productivity measures by examining data on TFP growth and partial productivity growth in selected Canadian natural resource-related industries.

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[19] Triplett (2006) provides a comprehensive overview of quality-adjustment methods.

[20] Byrne *et al.* (2016) ask whether unmeasured quality change can explain the recent productivity slowdown in the U.S. and find that it cannot. They do note that unmeasured quality change may be substantial even if it does not explain a trend growth decline. Their paper includes an overview of past research on the issue. A related problem is how to account for the introduction of new goods that deliver the same services as an old good at a different rate of service flow per unit. See Nordhaus (1996).

[21] The problem of comprehensiveness extends beyond environmental concerns. It is related to the longstanding critique of GDP per capita as a measure of welfare on the grounds that it excludes much (and perhaps most) of what matters for people's well-being.

III. Partial versus Total Factor Productivity: Empirical Analysis of Natural Resource Industries

This section presents data on TFP growth and a set of partial productivity measures for primary and secondary natural resource industries in Canada.[22] The primary industries are crop and animal production; forestry and logging; fishing, hunting and trapping; support activities for agriculture and forestry; oil and gas extraction; mining (except oil and gas); and support activities for mining and oil and gas extraction. The secondary industries are wood product manufacturing, paper manufacturing, and petroleum and coal product manufacturing. Natural resource industries were chosen because they are the industries for which environmental adjustment (of the sort being undertaken by the Smart Prosperity Institute) is particularly relevant.

Our purpose here is not to provide a comprehensive analysis of productivity in natural resource industries. Our results are intended to illustrate the variety of partial productivity measures that can be computed using available data and to highlight trends in the use of natural resources and ecosystems that are revealed by partial productivity measures but lost when inputs are combined in a TFP measure.[23] For detailed analysis of productivity trends and drivers in Canadian natural resources industries, readers are referred to the 20 reports that the Centre for the Study of Living Standards has published in this area over the past decade.[24]

The rest of the section is structured as follows. We first present estimates of TFP growth by industry. We then present and discuss estimates of the levels and growth rates of partial productivity measures for a variety of inputs: labour, capital, intermediate inputs, water, energy, and land. We end with a discussion of the adjustment of partial productivity measures to reflect the environmental costs of greenhouse gases emitted during the production process.

A. Trends in Total Factor Productivity by Industry

Chart 1 presents compound annual growth rates of TFP for Canada's major resource-related industries over the 1990-2012 period based on estimates from Statistics Canada.[25] The TFP growth estimates are computed by Statistics Canada using a version of the TFP growth formula discussed in Section II-A. Two sets of TFP growth estimates are presented in the chart: estimates based on value added and estimates based on gross output.[26] The estimates based on value added account for labour and capital input, while the estimates based on gross output account for capital, labour and intermediate inputs.

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[22] The data summarized in this section are available in a database at the following URL: http://www.csls.ca/reports/csls2016-20-database.xlsx.

[23] All the time series underlying the results reported in this section may be found in the database that accompanies this report. It is available at http://www.csls.ca/reports/csls2016-19-database.xlsx. That database also provides information about the sources of the data. The data are all drawn from Statistics Canada's CANSIM database.

[24] On agriculture, see de Avillez (2011a and 2011b), Ball, Nehring and Wang (2016), and Sheng, Ball and Nossal (2015); on forest products, see Harrison and Sharpe (2009), de Avillez (2014a and 2014b), Capeluck and Thomas (2015), and Thomas (2015); on oil and gas, see Bradley and Sharpe (2009b) and Sharpe and Waslander (2014a and 2014b); and on mining, see Smith (2004a, 2004b, and 2004c) and Bradley and Sharpe (2009a). For general studies on productivity and innovation in natural resource industries, see Centre for the Study of Living Standards (2004), Sharpe (2012) and Vernon and Kulys (2014).

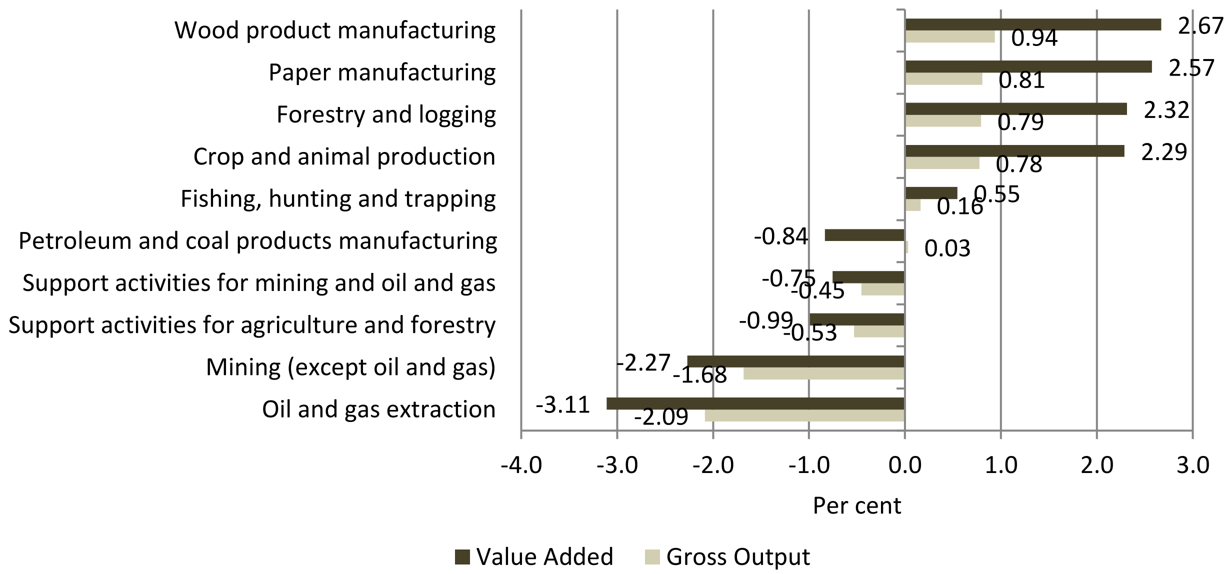
[25] See Baldwin and Gu (2013) for a general overview of Statistics Canada's multifactor productivity program.

[26] Gross output measures the total value of output produced by an industry, while value added measures the value of total output minus the value of intermediate inputs the industry purchases from other industries. To a close approximation, the growth rate of TFP based on value added is equal to TFP growth based on gross output divided by the share of primary (i.e. non-intermediate) inputs in total inputs. Since this share is between zero and one, the growth rate of TFP based on value added is always larger in absolute value than the growth rate of TFP based on gross output. This is shown in

Chart 1. See Diewert (2015) for a theoretical discussion of these concepts, and Calver (2015) for an empirical illustration of the two approaches.

There are significant differences across natural resource industries in terms of annual TFP growth. TFP based on value added declined by 3.11 per cent per year in the oil and gas extraction industry and by 2.27 per cent per year in the mining industry. These productivity declines may reflect the expansion of production into resource deposits that are costly to exploit as older, relatively cheap and accessible deposits had already been exploited. This explanation is consistent with declining capital productivity in both sectors, and with declining energy productivity in mining (though not in oil and gas). (Capital and energy productivity are discussed in more detail below.) Technological progress could have offset declining resource quality, but evidently this did not occur.

Chart 1: Total Factor Productivity based on Gross Output and Value Added, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



Source: Appendix Tables 8 and 12.

The fastest TFP growth over the period was in two resource-based manufacturing industries: wood product manufacturing (2.67 per cent per year) and paper manufacturing (2.57 per cent per year).

Forestry and logging and crop and animal production also exhibited robust TFP growth over the period. It is interesting to contrast these two industries with the mining and oil and gas extraction industries. All these industries depend on natural resource exploitation, but forestry and logging and crop and animal production are using their inputs more effectively over time while mining and oil and gas extraction are not. Again, this may reflect the deterioration of average resource quality in mining and oil and gas as high resource prices (until recently) made it profitable for firms to expand production using resource deposits of relatively low quality.

The TFP growth estimates based on gross output tell much the same story as those based on value added. The rank ordering of industries by TFP growth is nearly the same according to both measures; the only change is that petroleum and coal products manufacturing and support activities for mining and oil and gas switch order in fifth and sixth positions.

Since measured TFP is the ratio of real output to a unit-free index of inputs, a meaningful measure of the level of TFP is not available.

B. Trends in Partial Productivity Measures by Industry

For the same time period and set of industries as in

Chart 1, this subsection reports estimates of the following partial productivity measures: labour productivity, capital productivity, intermediate inputs productivity (where intermediate inputs include raw materials, energy and service inputs), water productivity, energy productivity, and land productivity. Estimates of both productivity levels and productivity growth rates are presented. The empirical results are themselves of interest to readers interested in resource industry productivity, but this is not intended to be a comprehensive analysis of productivity in Canada's natural resource industries. Our main aim is to emphasize that these partial productivity measures provide analytical insights about the efficiency with which specific resources are used, insights that cannot be gleaned from TFP growth alone.

i) Labour Productivity

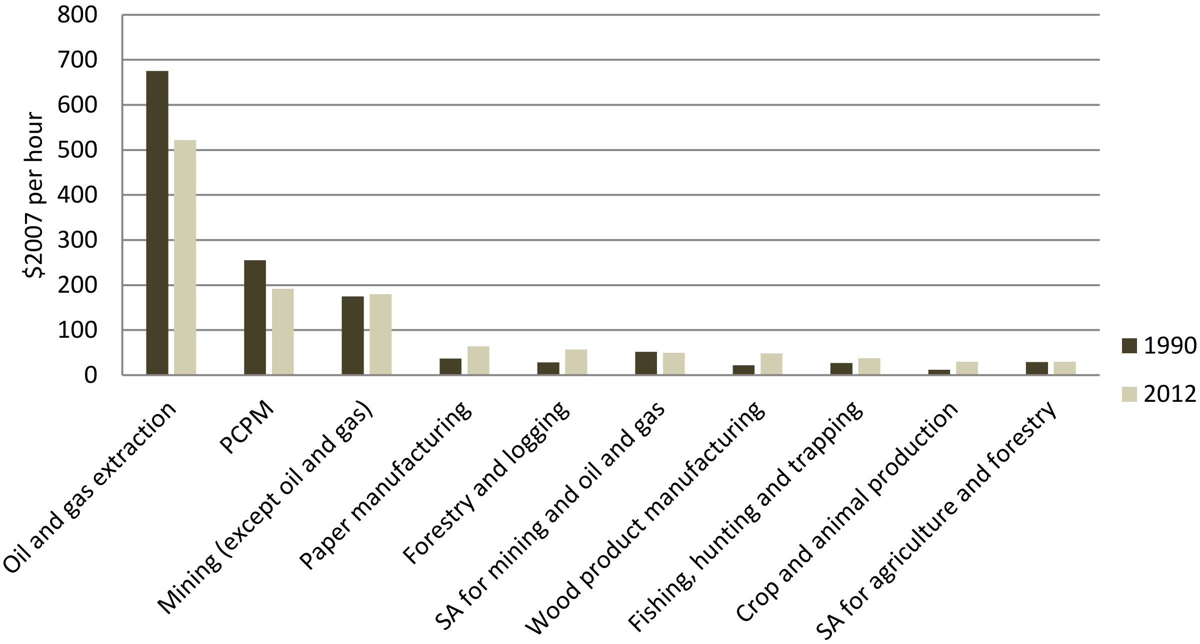
The most common partial productivity measure is labour productivity, or real output per hour worked. Again, output can be measured using either gross output or value added. Chart 2 depicts the data based on value added. In both 1990 and 2012, the level of labour productivity was much higher in the oil- and mining-related industries than in other industries. Labour productivity was highest in the oil and gas extraction industry in 2012, at $521.8 per hour.[27] The industry with the lowest level of labour productivity in 2012 was support activities for agriculture and forestry, at $29.7 per hour. The massive differences in labour productivity levels across natural resource industries reflect differences in economic rents and the capital intensity of production.

Chart 3 and Chart 4 present average annual growth rates of real output, hours worked, and labour productivity with real output measured by value added and gross output, respectively. As in the case of TFP growth, there is substantial variation in labour productivity growth across industries. On a value-added basis, labour productivity growth was highest in crop and animal production (4.17 per cent per year). Three industries exhibited negative labour productivity growth over the period: petroleum and coal products manufacturing (-1.28 per cent per year), oil and gas extraction (-1.17 per cent per year), and support activities for mining and oil and gas (-0.21 per cent per year).

As shown earlier, TFP growth is a contributor to labour productivity growth within a growth accounting framework.

[27] All dollar figures are measured in chained 2007 Canadian dollars.

Chart 2: Labour Productivity based on Value Added, Natural Resource Industries, $2007 per Hour, 1990 and 2012

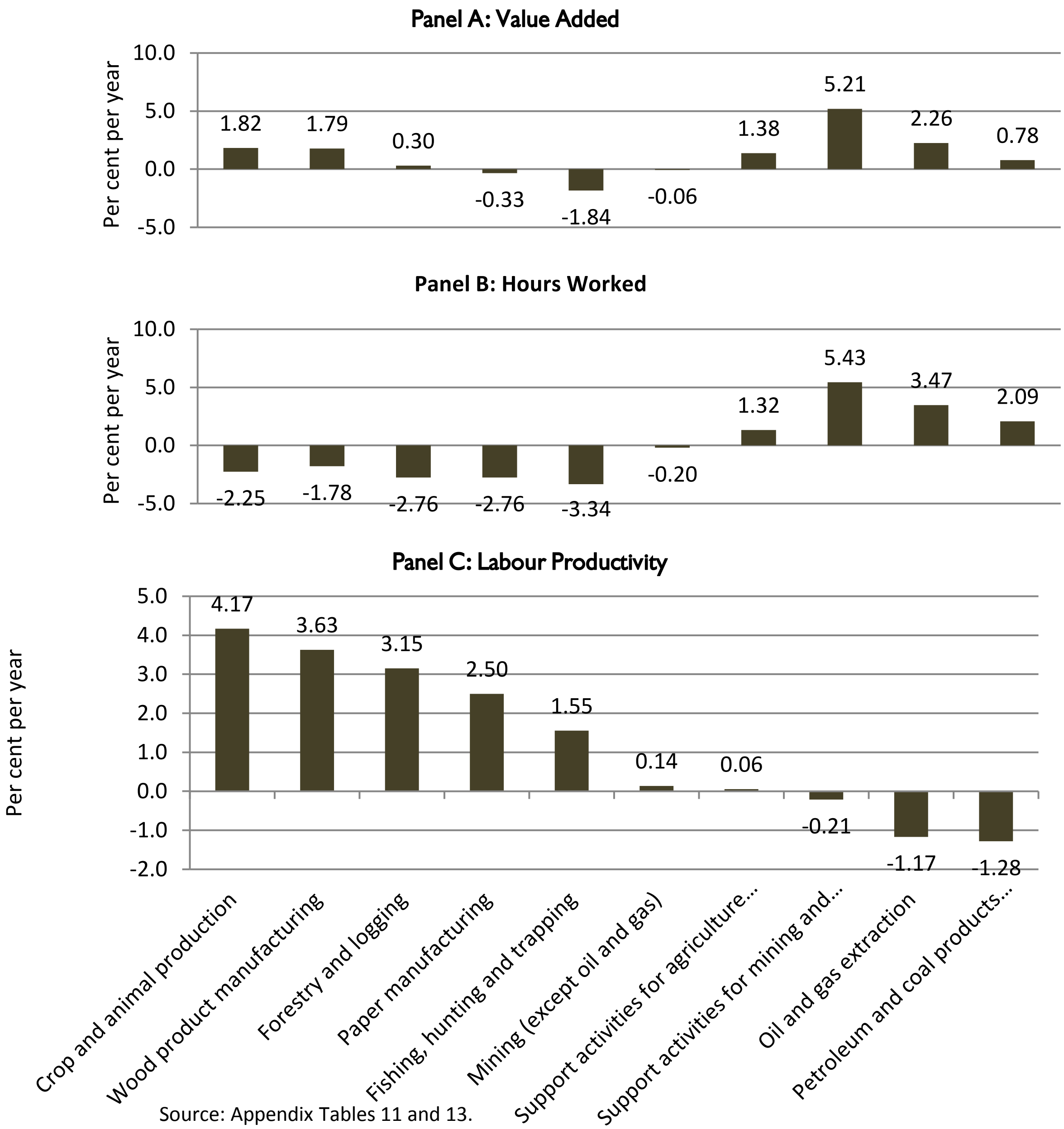


Note: PCPM = Petroleum and coal products manufacturing. SA = Support activities.
Source: Appendix Table 11.

Chart 1, Chart 3 and Chart 4 show that industries with high TFP growth also tended to have high labour productivity growth. Among the five industries that exhibited negative TFP growth on a value-added basis, three also had negative labour productivity growth. In the other two cases – mining (except oil and gas) and support activities for agriculture and forestry – capital deepening allowed those industries to use labour more productively in spite of negative TFP growth.

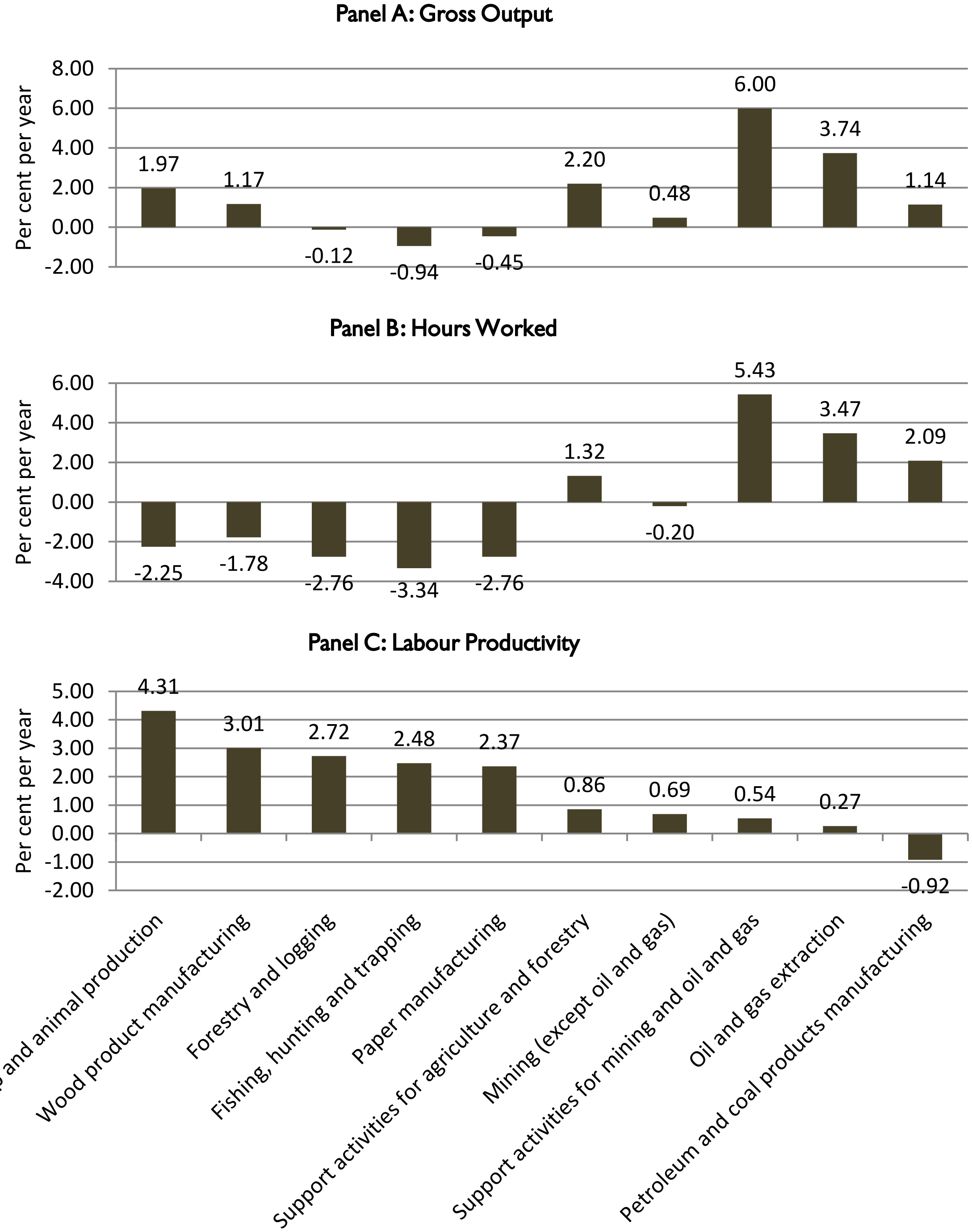
Industries differ in the extent to which their labour productivity performances have reflected changes in output or in labour input. The rapid labour productivity growth of the crop and animal production industry was driven by both positive output growth and falling hours worked, while that of the forestry and logging industry is entirely attributable to a decline in hours worked. The oil and gas industry and the support activities for mining and oil and gas industry each experienced both fast output growth and fast growth in hours worked, resulting in low rates of labour productivity growth.

Chart 3: Value Added, Labour Input, and Labour Productivity based on Value Added, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



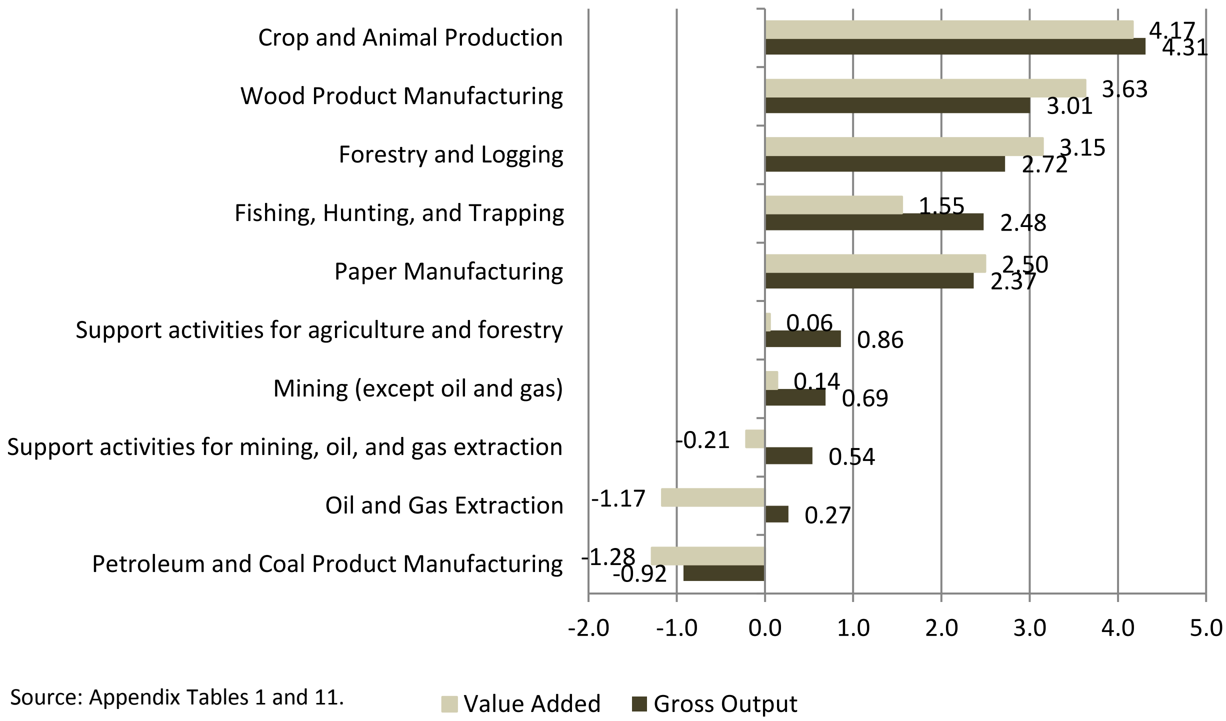
Source: Appendix Tables 11 and 13.

Chart 4: Gross Output, Labour Input, and Labour Productivity based on Gross Output, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



Source: Appendix Tables 1 and 3.

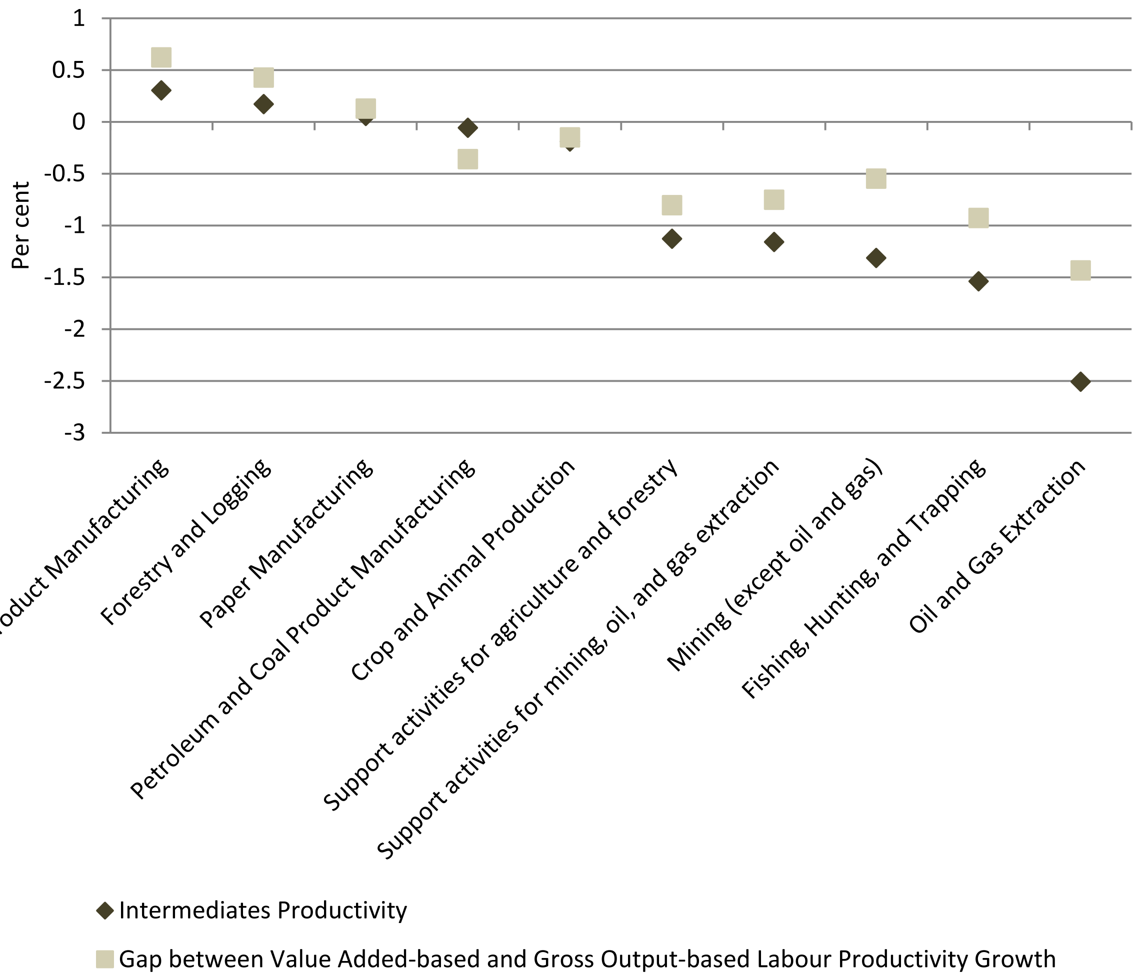
Chart 5: Labour Productivity based on Gross Output and Value Added, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



Source: Appendix Tables 1 and 11.

Chart 5 summarizes industry-level growth rates of labour productivity based on gross output and value added over the 1990-2012 period. The two sets of estimates tell much the same story. The small differences in the growth rates reflect the influence of intermediate inputs; labour productivity growth based on value added exceeds labour productivity growth based on gross output if the share of intermediate inputs in gross output falls. A falling share of intermediate inputs in gross output tends to be associated with rising intermediate goods productivity (as long as there are no large countervailing relative price changes). Chart 6 shows the strong positive correlation across industries between intermediate input productivity growth and the gap between value added-based and gross output-based labour productivity growth rates. Trends in intermediate input usage by industry are examined below (see Chart 8).

Chart 6: Intermediate Input Productivity Growth and the Gap between Value Added-Based and Gross Output-Based Labour Productivity Growth, Natural Resource Industries, Per Cent per Year, 1990-2012



Source: Appendix Tables 1, 9 and 11.

ii) Capital Productivity

Capital productivity is defined as real gross output per unit of capital services input.[28] Average annual growth rates of output, capital input, and capital productivity for each industry over the 1990-2012 period are depicted in Chart 7. Capital productivity grew fastest in the paper manufacturing industry (3.49 per cent per year), followed by crop and animal production (1.58 per cent per year) and wood product manufacturing (1.36 per cent per year). Support activities for agriculture and forestry had the lowest capital productivity growth, at -2.96 per cent per year.

The other industries that exhibited negative capital productivity growth over the period are those related to the mining and oil sector. Panel B of Chart 7 shows that these sectors had very high rates of capital input growth. Everything else being equal, the diminishing marginal product of capital implies that the average productivity of capital should be falling in these industries, and that is what Panel C shows. Rapid technological progress could have offset this effect by raising the marginal product of capital, but that did not occur. This is consistent with the fact that these industries all had zero or negative TFP growth rates.

iii) Intermediate Inputs Productivity

Chart 8 displays the annual growth rates of gross output, intermediate inputs, and intermediate input productivity for the ten industries over the 1990-2012 period. Intermediate inputs include raw materials, energy and purchased service inputs. Only three of the ten industries exhibited positive intermediate input productivity growth over the period: wood product manufacturing (0.30 per cent per year), forestry and logging (0.17 per cent per year) and paper manufacturing (0.06 per cent per year). The largest decline in intermediate input productivity occurred in oil and gas extraction, at -2.51 per cent per year.

The oil and gas extraction industry and the mining (except oil and gas) industry both exhibited rapid increases in intermediate input usage and negative growth rates of intermediate input productivity. Recall that these industries also had negative TFP growth and negative capital productivity growth over the 1990-2012 period. At the same time, both industries exhibited much faster labour productivity growth on a gross output basis than on a value added basis.

Taken together, these facts are informative about the drivers of productivity performance in the two industries over the 1990-2012 period. In these industries, output growth is being driven by increasing capital and intermediate inputs intensity. Rapid increases in the usage of these inputs have buttressed labour productivity growth (which was actually positive in mining and, in gross output terms, in oil and gas extraction), and this redounded to the benefit of workers given the link between labour productivity and wages. However, the pace of technological progress has been insufficient to maintain the average productivity of capital and intermediate inputs. This is reflected in the deterioration of TFP in the two industries (though we must keep in mind that TFP growth is an imperfect indicator of technological change).

The preceding discussion is an example of the way in which partial and total factor productivity measures, interpreted together, provide more insight about industry-level trends than TFP alone would have yielded.

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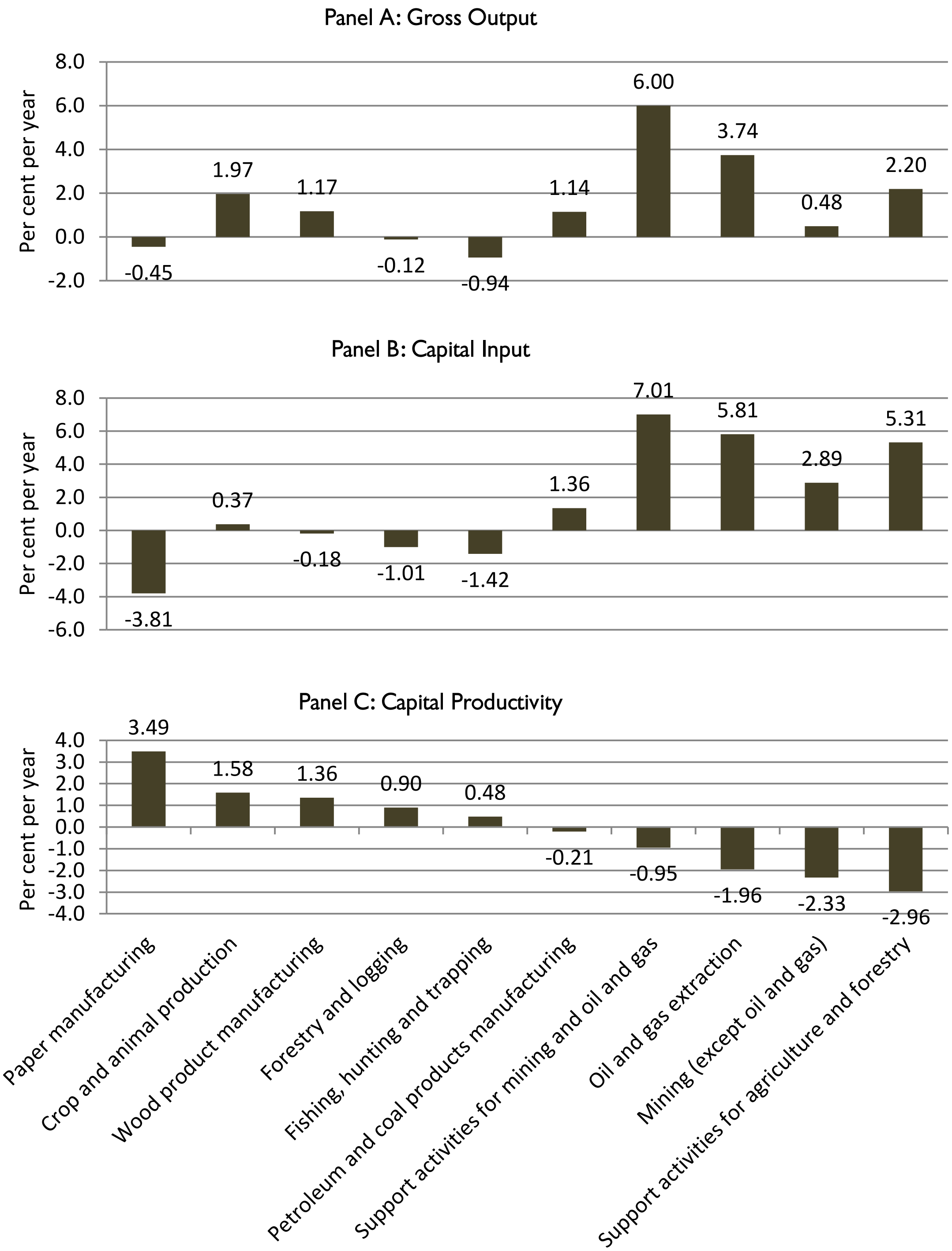
[28] In the remaining sections of this paper, we focus on productivity measures based on gross output. Productivity measurement based on value added are meaningful only in the cases of labour productivity, capital productivity, and TFP. Estimates of capital productivity growth based on value added are presented in

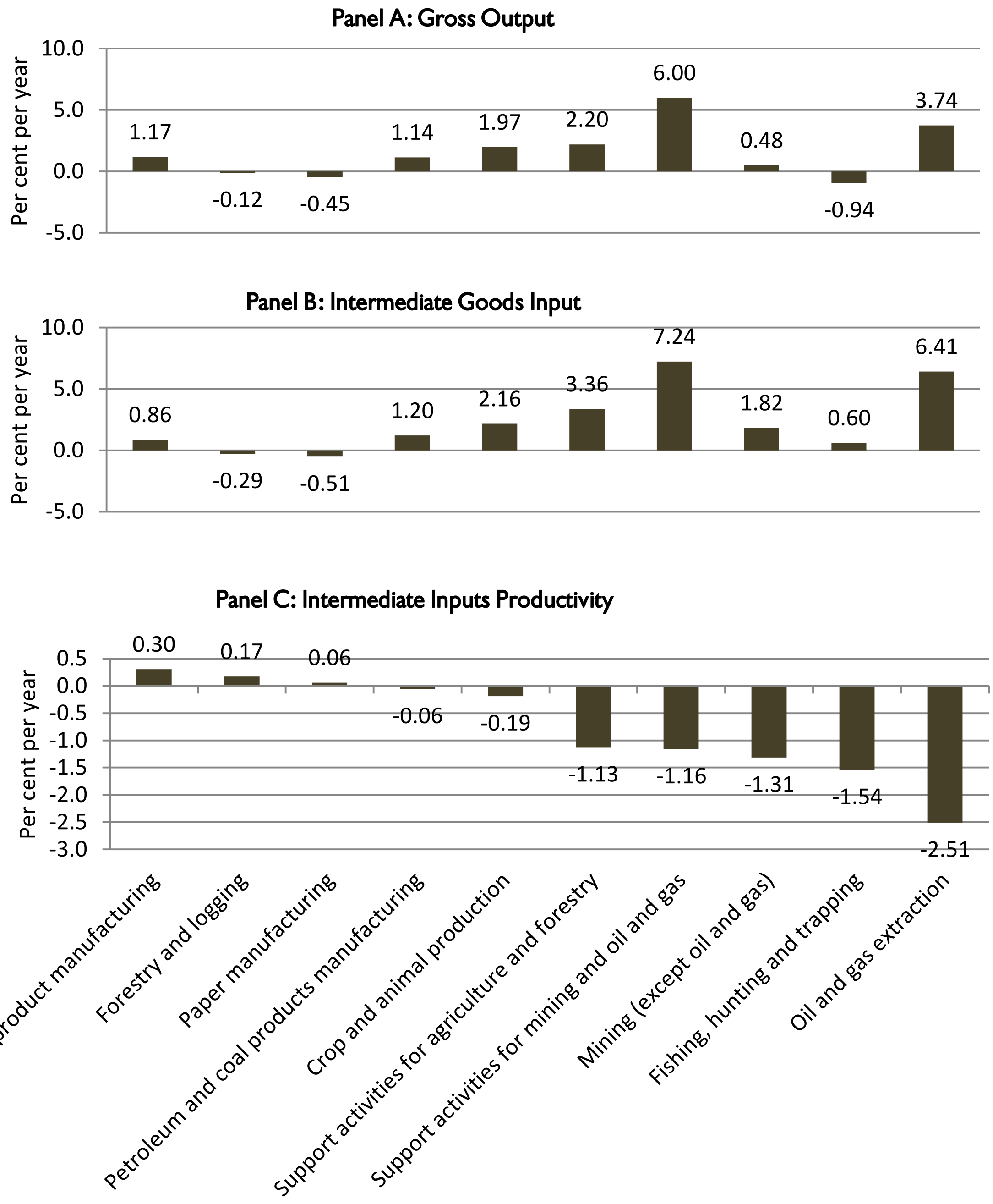
Table 3 below, but since they tell the same story as the gross output-based estimates, we do not discuss them here.

Chart 7: Gross Output, Capital Input, and Capital Productivity, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



Source: Appendix Tables 2 and 3.

Chart 8: Gross Output, Intermediate Inputs, and Intermediate Input Productivity, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



Source: Appendix Tables 3 and 9.

iv) Water Productivity

An advantage of partial productivity measures is that they allow us to focus on trends in the efficiency with which industries are using specific resource inputs of special interest. One such input is water. Table 1 presents measures of gross output growth, water input growth, and water productivity growth in recent years for the eight industries for which water input data are available. Water productivity growth is highly variable across industries as a result of the high cross-industry variance of water input usage. This in turn reflects differences in the production processes used in different industries, some of which require more water than others. In industries that use little water, small absolute changes in water input usage translate into large per cent changes in water usage and in water productivity.

Table 1: Gross Output, Water Input, and Water Productivity, Natural Resource Industries, Levels and Compound Annual Growth Rates, 2005-2012

	Growth rates (per cent per year)			Level (millions of 2007 dollars per thousand cubic metres)
	Gross Output Growth	Water Input Growth	Water Productivity Growth	Water productivity Level, 2012
Crop and animal production	1.07	0.26	0.81	0.03
Forestry and logging[a]	-3.89	15.48	-16.77	17.19
Oil and gas extraction	1.30	5.35	-3.85	0.36
Mining (except oil and gas)[a]	-0.21	2.82	-2.94	0.07
Support activities for mining and oil and gas[a]	5.79	34.82	-21.53	819.68
Wood product manufacturing	-5.42	-22.53	22.08	0.97
Paper manufacturing	-4.38	-8.13	4.07	0.02
Petroleum and coal products manufacturing	0.07	-4.33	4.61	0.25

a. The period is 2008-2012 for these industries due to data availability.
Source: Appendix Tables 3 and 5.

Three of the industries exhibited annual growth rates of water input that were in the double digits (in magnitude). In two of those industries − support for activities in mining and oil and gas and forestry and logging − this may reflect the fact that the industries use a low absolute quantity of water input, so that small absolute changes translate into large proportional changes. For the third, the wood products manufacturing industry, this was not the case. That industry's water use was 135.5 million cubic metres in 2005 − of the same order of magnitude as the water usage of the oil and gas extraction industry, for example − but plummeted to 22.7 million cubic metres in 2012. Even though real output in wood products manufacturing was also falling over the 2005-2012 period, the massive decline in water usage resulted in annual water productivity growth of 22.03 per cent, by far the highest among any of the resource industries.

In general, the natural resource-based manufacturing industries experienced substantial water productivity improvements in recent years while the primary resource industries saw water productivity declines.

The last column of the table contains estimates of the level of water productivity in each industry in 2012. The support activities for mining and oil and gas industry and the forestry and logging industry are outliers; again, this reflects the fact that these industries use very little water input. Among the remaining industries, wood products manufacturing had the highest level of water productivity. Thus, wood products manufacturing is a high-performing industry in terms of both the level and the growth rate of water productivity.

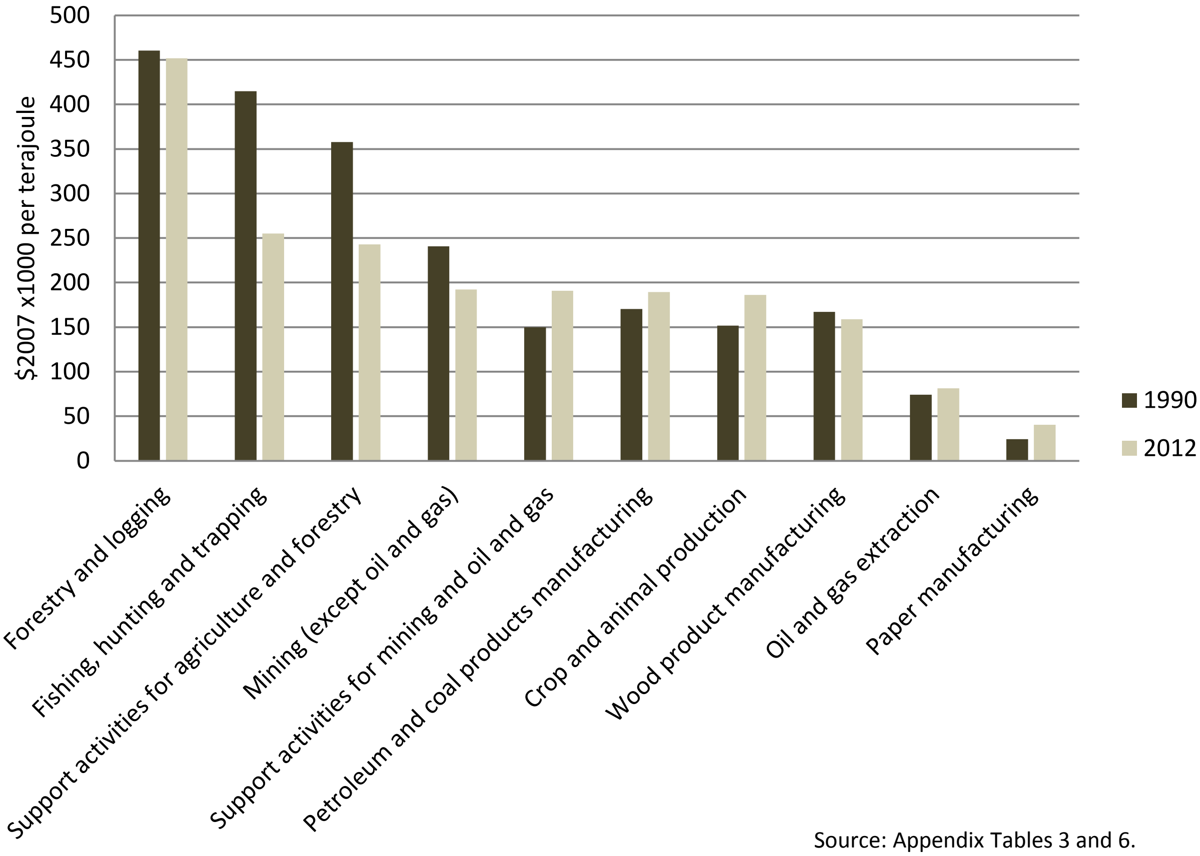
v) Energy Productivity

Another input of special importance from the perspective of environmental sustainability is energy, which includes both electricity (from all sources) and gasoline and other fossil fuels. Energy productivity is defined as gross output divided by energy input measured in terajoules.

Forestry and logging had the highest level of energy productivity in 2012, at $452 thousand per terajoule (Chart 9). It was followed by fishing, hunting and trapping ($255.2 thousand per terajoule) and support activities for agriculture and forestry ($243.1 thousand per terajoule). These industries use little energy input relative to the others. Paper manufacturing had the lowest energy productivity in 2012, at $40.6 thousand per terajoule.

Chart 10 presents the growth rates of output, energy input and energy productivity for the major resource industries. Paper manufacturing exhibited the fastest rate of energy productivity growth over the 1990-2012 period, at 2.38 per cent per year. The largest declines in energy productivity were in fishing, hunting and trapping (-2.18 per cent per year) and in support activities for agriculture and forestry (-1.74 per cent per year).

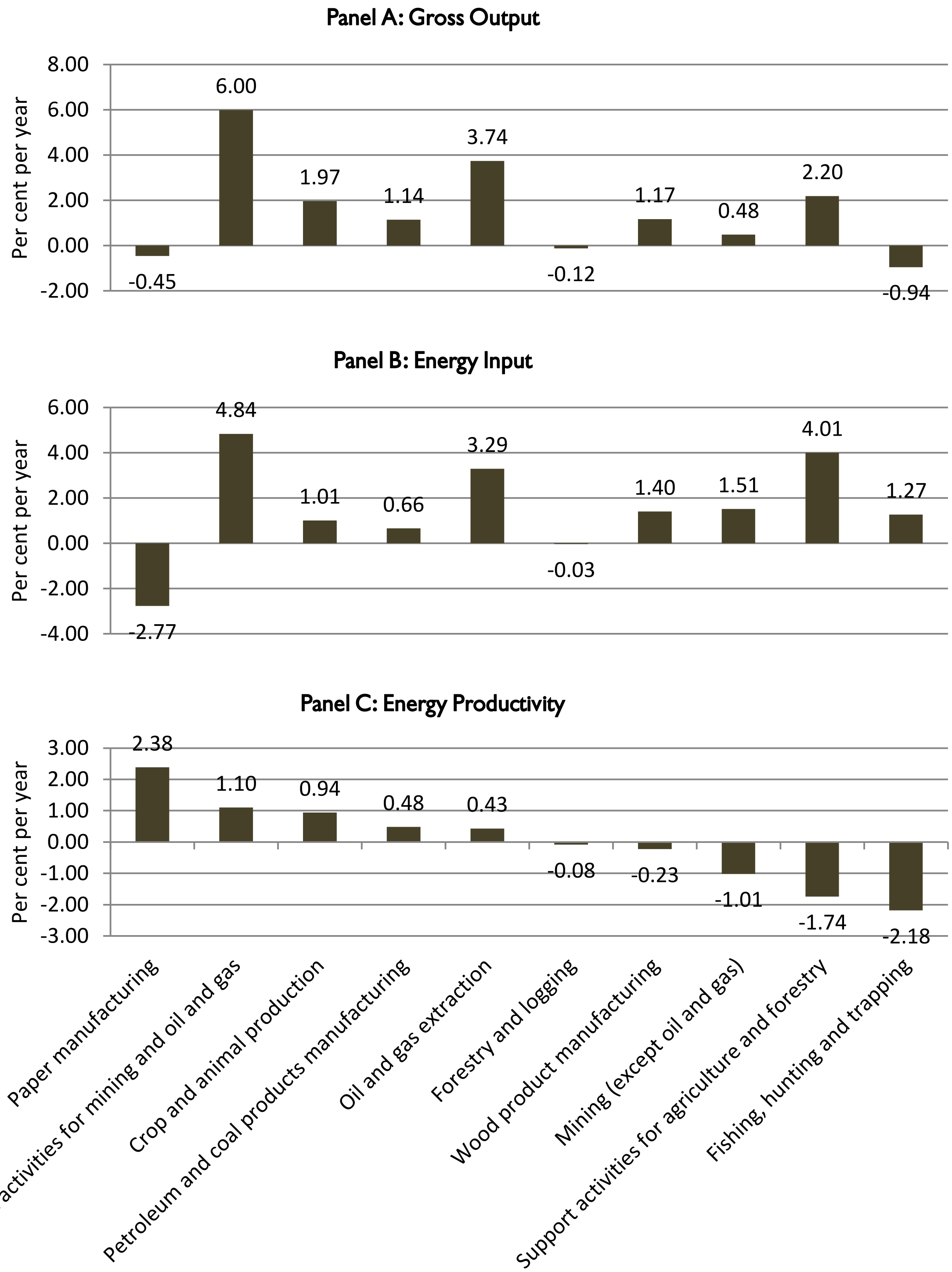
Chart 9: Energy Productivity, Natural Resource Industries, Thousands of $2007 per Terajoule, 1990 and 2012



Source: Appendix Tables 3 and 6.

In contrast to the earlier findings for capital productivity, the industries associated with the oil and gas sector exhibited positive energy productivity growth. These industries did not cut energy usage; each exhibited robust growth in energy input (Chart 10, Panel B). But output grew faster (Panel A). This may reflect rising capital intensity. Indeed, a comparison of Panel B of Chart 10 with Panel B of Chart 7 indicates that these industries experienced rising capital input per terajoule of energy input. This may reflect, for example, fuel efficiency gains in trucks and other forms of capital equipment.

Chart 10: Gross Output, Energy Input, and Energy Productivity, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012

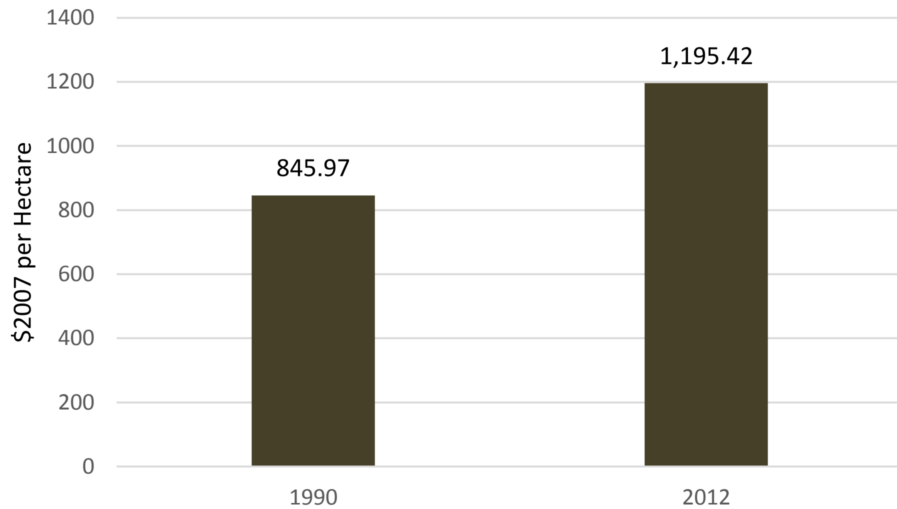


Source: Appendix Tables 3 and 6.

vi) Land Productivity

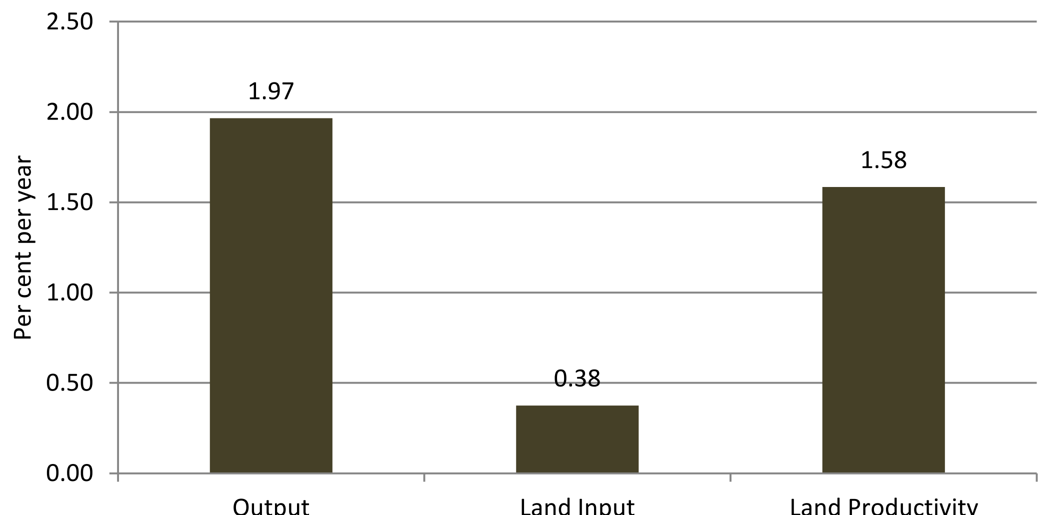
Land is an important input in agriculture. Agricultural land input is measured in hectares and is the sum of land in crops and tame or seeded pasture.[29] Land productivity in the crop and animal production industry was $1,195 per hectare of land in 2012, up from $846 in 1990 (Chart 11).

Chart 11: Land Productivity, Crop and Animal Production Industry, $2007 per Hectare, 1990 and 2012



Source: Appendix Tables 3 and 4.

Chart 12: Gross Output, Land Input, and Land Productivity, Crop and Animal Production Industry, Compound Annual Growth Rates, 1990-2012



Source: Appendix Tables 3 and 4.

[29]Statistics Canada defines 'tame or seeded pasture' as "grazeable land that has been improved from its natural state by seeding, draining, irrigating, fertilizing or weed control."

Land input grew by 0.38 per cent per year in the crop and animal production industry over the 1990-2012 period, while gross output increased by 1.97 per cent per year. As a result, agricultural land productivity increased by 1.58 per cent per year over the period (Chart 12). Note that land input is the amount of land actually used in production; growth in land input does not imply that new arable land is being created (although one implication of climate change may be that land at higher latitudes will become suitable for agricultural use). An increase in land input could reflect, for example, a decrease in the use of fallow by farmers.

In addition, these land productivity growth estimates include the effect of changes in land quality. Land quality is an important determinant of agricultural productivity, but our data on land input is not adjusted for quality.[30] Thus, quality changes are counted as changes in productivity.

vii) Productivity and the Pollution Intensity of Production

Production processes often generate pollution as a byproduct. As noted at the end of Section II, a comprehensive notion of productivity would account for this output of 'economic bads' in addition to the output of economic goods and services captured by conventional productivity measures. To see how this can be done, let $A_{i,t}^{E}$ denote an environmentally adjusted partial productivity measure for input i at time t. Let it be defined as

$$A_{i,t}^{E} = \frac{Q_t - \rho_t G_t}{X_{i,t}}$$

Following our notation from Section II, Q_t is the firm's real output and $X_{i,t}$ is the firm's use of input i. The new components are G_t, a measure of the quantity of pollution (e.g. tons of greenhouse gas emissions), and ρ_t is a weight reflecting the real price of pollution (e.g. an estimate of the social cost of carbon). The expression above can be rewritten as

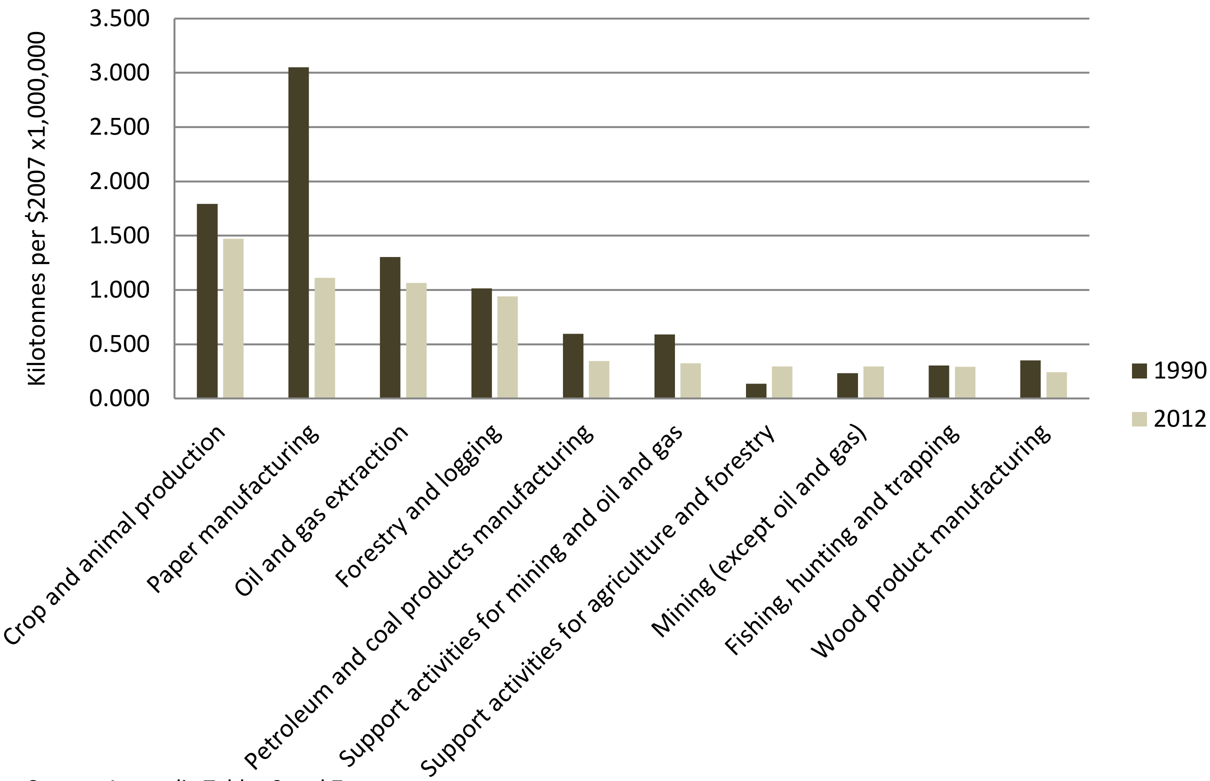
$$A_{i,t}^{E} = A_{i,t}(1 - \rho_t \frac{G_t}{Q_t})$$

where $A_{i,t}$ is the conventional partial productivity measure $\frac{Q_t}{X_{i,t}}$ we have been discussing all along and $\frac{G_t}{Q_t}$ is a measure of the pollution intensity of production. Falling pollution intensity indicates that the industry's production process is growing cleaner.[31]

[30] For a comprehensive analysis of productivity in the agriculture industry, see de Avillez (2011a; 2011b).

[31] Note, however, that this measure captures pollution emitted per unit of output during the industry's production process. It does not capture the pollution that may have been emitted during the production of produced inputs now being used as part of the production process.

Chart 13: Greenhouse Gas Intensity, Natural Resource Industries, Kilotonnes of Carbon Dioxide Equivalent per Million $2007 of Output, 1990 and 2012

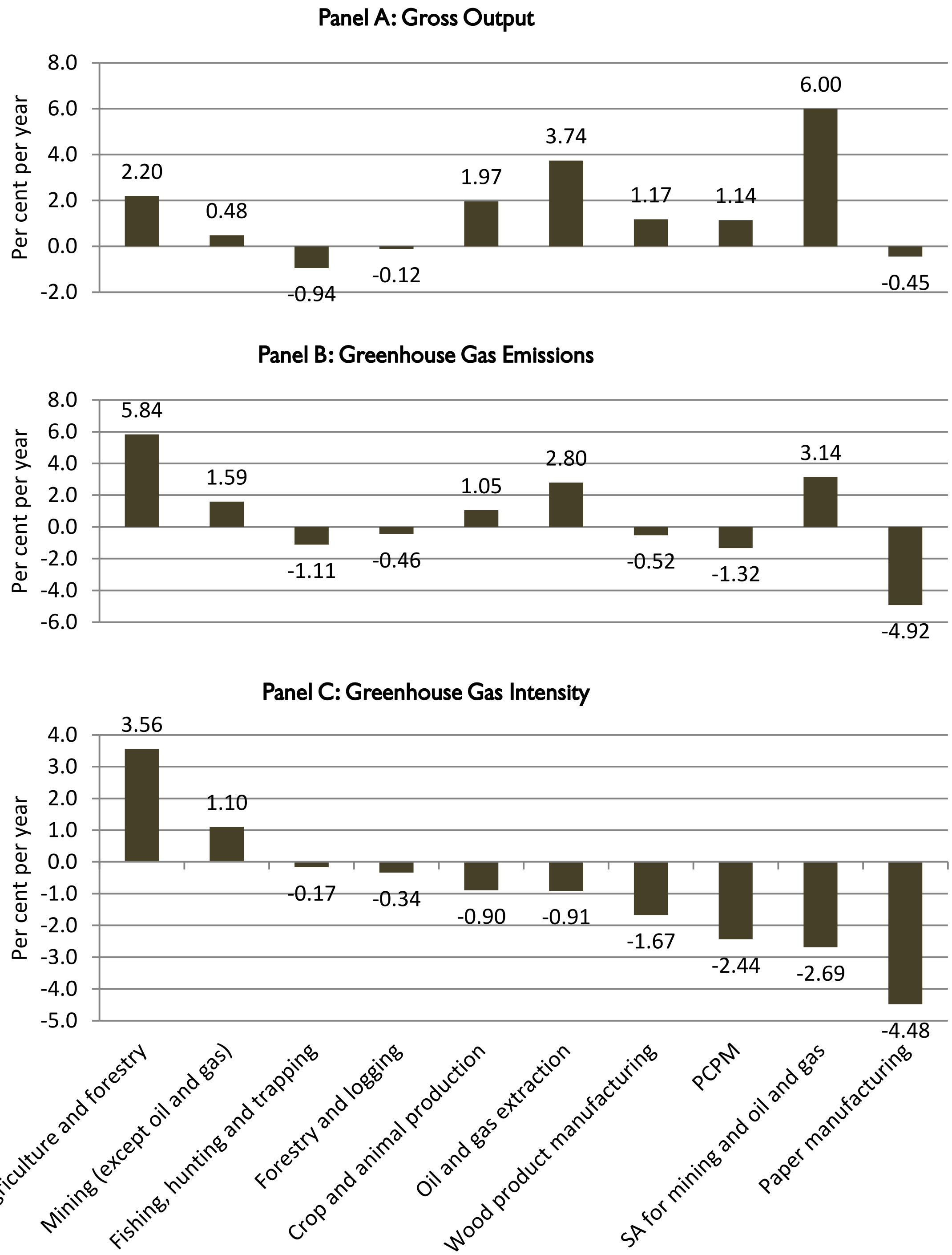


Source: Appendix Tables 3 and 7.

The expression above shows how a partial productivity measure can be adjusted to reflect the cost of the environmental damages arising from pollution. In this report, we will not take a stand on the value of ρ_t, the social cost of pollution. As a first pass at assessing the 'dirtiness' of an industry's production process, we will examine a measure of pollution intensity, $\frac{G_t}{Q_t}$, for a particular pollutant: greenhouse gas emissions, measured in kilotonnes of CO_2-equivalent. There are many pollutants other than greenhouse gases, of course, including particulate matter in the air, chemical refuse, industrial waste, nuclear radiation, and garbage, among others. Nevertheless, we think it valuable to focus on greenhouse gases given the importance of global climate change as a policy issue.

The wood products manufacturing industry had the lowest level of greenhouse gas intensity in 2012, at 0.24 kilotonnes per unit of output (in millions of 2007 dollars), followed by the fishing, hunting and trapping industry and the mining (except oil and gas) industry, both at 0.29 kilotonnes per unit of output (Chart 13). The highest greenhouse gas intensity level was in crop and animal production, at 1.5 kilotonnes per unit, followed by paper manufacturing and oil and gas extraction, each at 1.1 kilotonnes per unit.

Chart 14: Gross Output, Greenhouse Gas Emissions, and Greenhouse Gas Intensity, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



Note: PCPM = Petroleum and coal products manufacturing. SA = Support activities.
Source: Appendix Tables 3 and 7.

Greenhouse gas intensity decreased the most over the 1990-2012 period in the paper manufacturing industry (4.48 per cent per year), followed by support activities for mining and oil and gas at 2.69 per cent per year (Chart 14). Greenhouse gas intensity in paper manufacturing fell because greenhouse gas emissions declined faster than output, while in support activities for mining and oil and gas, both output and emissions increased but output grew faster.

Greenhouse gas intensity increased in only two industries: support activities for agriculture and forestry, at 3.56 per cent per year, and mining (except oil and gas), at 1.10 per cent per year. All other industries experienced negative greenhouse gas intensity growth over the period (i.e. their production processes became cleaner on a per-unit basis), including the oil and gas industry and the petroleum and coal products manufacturing industry. The latter saw an absolute decline in its level of emissions while output increased.

viii) Summary

The objective of this subsection is to summarize the insights on resource use and efficiency that the different productivity measures provide. To that end, Table 2 and Table 3 bring together all the productivity measures for the ten natural resource industries included in this report based on value added and gross output, respectively. We first outline a number of general relationships between productivity concepts that have been mentioned earlier in the report, with illustrations from natural resource industries. Second, we provide general observations on productivity trends in natural resource industries in Canada. Third, we highlight observations about productivity dynamics in Canadian natural resource industries that might be missed if TFP were the sole focus of analysis.

Observations about productivity concepts and the relationships between them

The productivity growth estimates we have presented in this section exhibit several properties that were discussed earlier in the paper. These include the following:

1) Value added-based TFP measures generally exhibit larger TFP growth rates in absolute magnitude than gross output-based TFP measures.[32] Intermediate goods usage tends to grow in line with the growth of gross or physical output (intermediate goods/gross ratios are fairly stable). This means intermediate goods, which have a large weight in the total value of gross output, tend to grow faster than labour input, boosting total input growth and dampening TFP growth. The extent of the dampening is determined by the share of intermediate goods in gross output, the greater the share the greater the dampening.

2) The difference between the growth rate of labour productivity measured on a value added basis and on a gross output basis is the size of the change in ratio of intermediate goods to gross output. This latter relationship is called intermediate goods intensity and is inversely related to intermediate goods productivity. In industries where there are large increases in the relative use of intermediates gross (i.e. falls in intermediate goods productivity), labour productivity on a gross output basis exhibits faster growth than on a value added basis. For example, the oil and gas extraction sector saw intermediate goods productivity fall 2.5 per cent per year between 1990 and 2012 as growth in intermediate inputs raised the ratio of intermediate inputs to gross output grew from 50 cent to 60 per cent. This resulted in faster growth in gross output than in value added and with the same growth in labour input for both labour productivity measures, faster growth in gross output based labour productivity compared to value added-based labour productivity (0.27 per cent versus -1.17 per cent).

[32]Larger in the sense of the absolute value of the productivity growth rate. If gross output-based TFP growth is negative value added-based TFP growth will be even more negative.

Table 2: Productivity Measures based on Gross Output, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012

Productivity Growth, 1990 to 2012 (per cent per year)	TFP	Labour Productivity	Capital Productivity	Intermediate Goods Productivity	Water Productivity*	Energy Productivity	Land Productivity	GHG Emissions Intensity
Primary Resource Industries								
Crop and Animal Production	0.78	4.31	1.58	-0.19	3.12	0.94	1.58	-0.90
Forestry and Logging ∏	0.79	2.72	0.90	0.17	-13.17	-0.08	-	-0.34
Fishing, Hunting, and Trapping	0.16	2.48	0.48	-1.54	-	-2.18	-	-0.17
Support activities for agriculture and forestry	-0.53	0.86	-2.96	-1.13	-	-1.74	-	3.56
Oil and Gas Extraction	-2.09	0.27	-1.96	-2.51	-3.85	0.43	-	-0.91
Mining (except oil and gas)	-1.68	0.69	-2.33	-1.31	-2.94	-1.01	-	1.10
Support activities for mining, oil, and gas extraction	-0.45	0.54	-0.95	-1.16	-17.63	1.10	-	-2.69
Secondary Resource Industries								
Wood Product Manufacturing	0.94	3.01	1.36	0.30	22.08	-0.23	-	-1.67
Paper Manufacturing	0.81	2.37	3.49	0.06	4.07	2.38	-	-4.48
Petroleum and Coal Product Manufacturing	0.03	-0.92	-0.21	-0.06	4.61	0.48	-	-2.44
Average (Unweighted)	-0.12	1.48	1.55	-0.74	-0.46	0.01	1.58	-0.89
Standard Deviation	1.07	2.11	1.86	0.93	12.20	1.38	-	2.21

GHG Emissions Intensity is the ratio of emissions of Greenhouse Gases (in kilotonnnes of carbon dioxide equivalents) to Real Gross Output

* Water productivity figures are calculated from 2005 to2012, unless only available from 2008 to 2012, as indicated by ∏

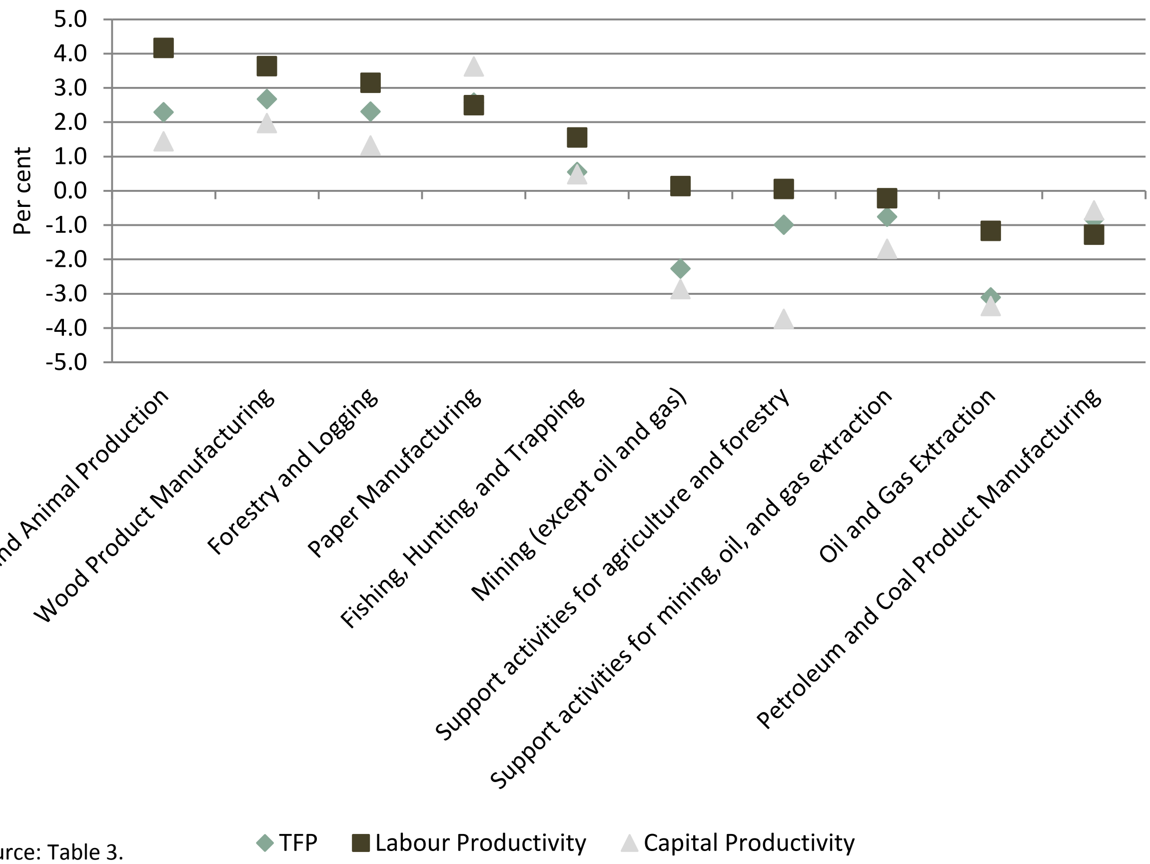
Source: Appendix Table S-1.

Table 3: Productivity Measures based on Value Added, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012

Productivity Growth, 1990 to 2012 (per cent per year)	TFP	Labour Productivity	Capital Productivity	GHG Emissions Intensity
Primary Resource Industries				
Crop and Animal Production	2.29	4.17	1.44	-0.76
Forestry and Logging	2.32	3.15	1.32	-0.76
Fishing, Hunting, and Trapping	0.55	1.55	0.48	-0.17
Support activities for agriculture and forestry	-0.99	0.06	-3.73	4.39
Oil and Gas Extraction	-3.11	-1.17	-3.36	0.53
Mining (except oil and gas)	-2.27	0.14	-2.86	1.66
Support activities for mining, oil, and gas extraction	-0.75	-0.21	-1.69	-1.96
Secondary Resource Industries				
Wood Product Manufacturing	2.67	3.63	1.97	-2.27
Paper Manufacturing	2.57	2.50	3.62	-4.61
Petroleum and Coal Product Manufacturing	-0.84	-1.28	-0.57	-2.08
Aggregate Business Sector	0.10	1.38	-1.00	-
Average (Unweighted)	0.24	1.25	-0.34	-0.60
Standard Deviation (excluding Aggregate Business Sector)	2.14	2.01	2.51	2.46

GHG Emissions Intensity is the ratio of emissions of Greenhouse Gases (in kilotonnnes of carbon dioxide equivalents) to Real Gross Output.
Source: Appendix Table S-2.

Chart 15: TFP, Labour Productivity and Capital Productivity based on Value Added, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



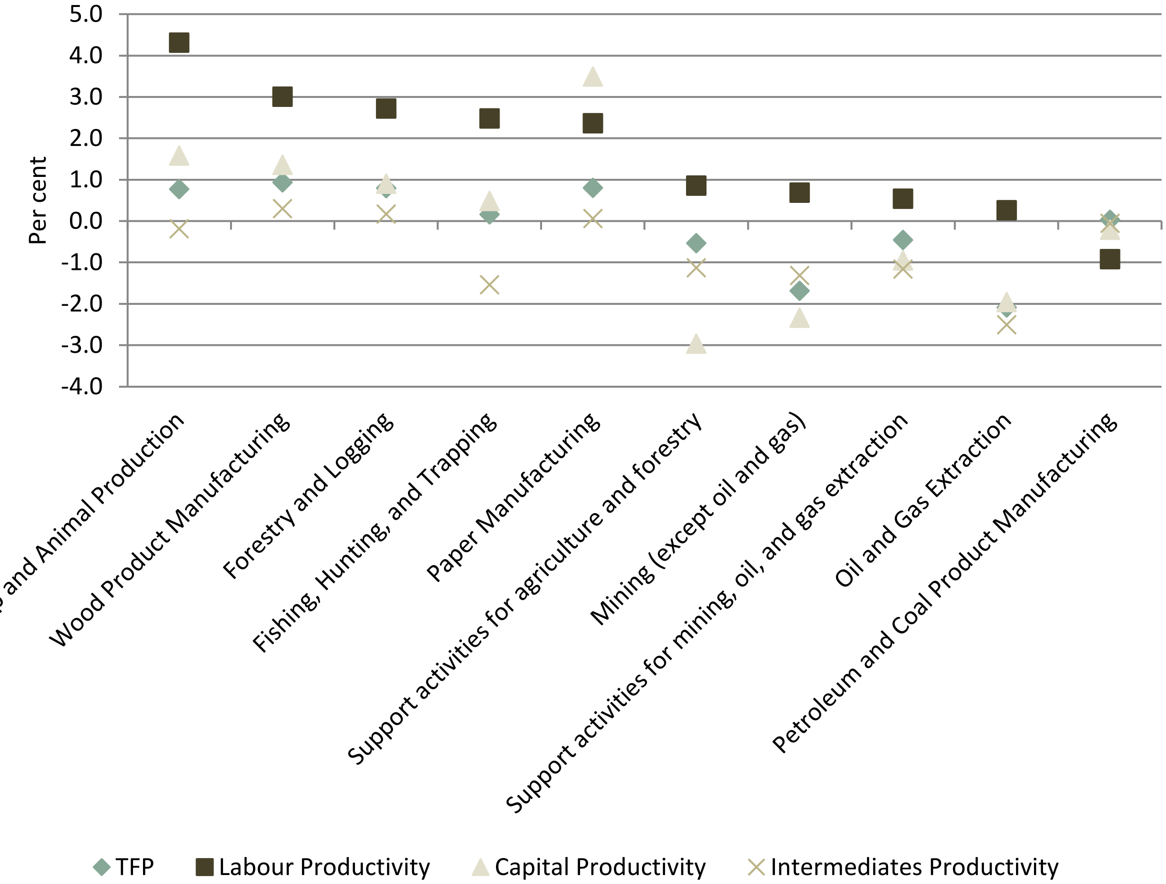
Source: Table 3.

3) In Section II-A, we noted that TFP growth is a weighted average of partial productivity growth rates. On a value added basis, TFP growth will always lie between the growth rates of labour productivity and capital productivity. On a gross output basis, TFP growth will be a weighted average of the growth rates of labour productivity, capital productivity, and intermediate goods productivity. Indeed, the numbers in Table 2 and Table 3 are consistent with these theoretical properties.[33] Chart 15 and Chart 16 illustrate these relationships graphically for productivity measures based on value added and gross output, respectively.

4) The variance of TFP growth across industries is typically smaller than the average variance of the partial productivity measures. This is not surprising, given that TFP growth is a weighted average of partial productivity growth rates.

[33] A puzzling exception is that, according to Statistics Canada data, gross output-based TFP growth in petroleum and coal product manufacturing is positive while the partial productivity growth rates for labour, capital and intermediate inputs are all negative in that industry (Summary Table 1).

Chart 16: TFP, Labour Productivity, Capital Productivity and Intermediate Input Productivity based on Gross Output, Natural Resource Industries, Compound Annual Growth Rates, 1990-2012



Source: Table 2.

5) Conventional productivity measures do not account for environmental impacts of production. To assess trends in the production of economic “bads” such as greenhouse gases, one must track their output in relation to conventional output. Between 1990 and 2012, greenhouse gas intensity improved (i.e. declined) in eight of the ten natural resource industries. The exceptions were support activities for agriculture and forestry and mining (except oil and gas).

Productivity trends in Canadian natural resource industries

1) Observed productivity growth rates in the ten industries that make up the Canadian natural resource sector varied widely over the 1990-2012 period. Annual TFP growth on a value added basis ranged from 2.7 per cent in wood products to -3.1 per cent in oil and gas extraction.

2) The three forestry products industries (forestry and logging, wood products manufacturing, and paper products manufacturing) and crop and animal production were the four natural resource industries that exhibited the best productivity performance over the 1990-2012 period across both TFP and partial productivity measures, whether based on value added or gross output. Oil and gas extraction experienced the worst productivity performance, followed by mining.

3) Despite the rise in energy prices over the 1990-2012 period, one half of the ten natural resource industries saw falls in their level of energy productivity; that is, negative energy productivity growth as energy use grew faster than gross output.

4) On the other hand, the intensity of greenhouse gas emissions fell significantly in eight of the ten natural resources industries on a gross output basis and in seven industries on a value added basis.

5) The productivity measure with the largest variance in growth across industries by far was water productivity. Four of the eight industries for which data are available enjoyed reductions in water usage per unit of gross output. Wood product manufacturing exhibited massive improvements in water productivity (22.1 per cent per year) while support activities for mining and oil and gas extraction had a massive deterioration (-17.6 per cent).

What a focus on TFP ignores

TFP measures may be a useful bottom line for assessing trends in the efficiency of overall resource usage in the production process in natural resource industries. But this summary statistics misses or ignore much useful information on resource use in these industries. Some examples are below.

1) A focus on TFP provides no insight regarding the efficiency with which firms are using particular inputs that may be of special interest. Partial productivity measures can provide such information.
   i. Labour productivity allows data users to calculate labour requirements for a given amount of output. This is useful for human resource planning purposes.
   ii. Energy productivity measures allow for the assessment of trends in energy efficiency, which is closely linked to greenhouse gas emissions.

2) Since TFP measures may not include certain inputs, such as land, because of data constraints, they may provide an incomplete picture of trends in overall resource usage.

3) Partial productivity measures can help to understand the proximate sources of negative TFP growth, which is surprisingly found to have occurred in one half of the natural resource industries over the 1990-2012 period in Canada for both value added-based TFP and gross output-based TFP. To the extent that TFP growth reflects technical change (and remember that this interpretation is subject to many caveats), negative TFP growth suggests technical regress, which seems implausible. Partial productivity measures reveal that that negative TFP growth in these industries is generally (though not always) associated with negative capital productivity growth.

IV. Conclusion

The aim of this report is to make the case that an assessment of industry productivity trends is best carried out on the basis of a suite of productivity measures including both total factor productivity (TFP) and partial productivity measures. Efforts to create improved productivity measures that account for factors such as natural capital should incorporate both TFP and partial productivity measurement, rather than focus on TFP alone.

TFP is important because of its central role as the driver of long-run growth in the neoclassical growth model. In addition, it is useful within the neoclassical growth accounting framework because it is a source of the growth of partial productivity measures. However, TFP measurement brings a number of theoretical and practical challenges. These include:

- TFP is not a measure of technical progress, though it is often interpreted as such. At best, it measures the costless part of technical change. When various stringent assumptions do not hold, standard TFP measures capture a number of non-technological effects and these complicate its interpretation.

- The data requirements for TFP measurement are burdensome compared to those of partial productivity measurement. Unmeasured and un-marketed inputs present particular challenges.

- TFP measurement is sensitive to certain methodological choices about which there is no widespread consensus. Reasonable analysts can disagree about what methods are most appropriate, and the effect on TFP measures can be quantitatively large.

- The complexity of the methods, the subtlety of interpretation, and the fact that it can be measured in growth rates but not in levels make TFP difficult to explain to the general public compared to partial productivity measures.

Partial productivity measures are less affected by these challenges. A partial productivity measure requires less data and is less sensitive to theoretical and methodological assumptions. It can be estimated in either levels or growth rates, and it has an intuitive interpretation that non-experts can grasp with relative ease. Theory implies a direct link between partial productivity measures and factor payments; in particular, labour productivity is relevant for average wages and, hence, for living standards.

Neither TFP nor a partial productivity measure, by itself, provides a complete picture of productivity trends. TFP growth and partial productivity growth are related within the growth accounting framework, and a complete understanding of productivity growth is best achieved by examining TFP and partial productivity measures together. Moreover, particular partial productivity measures are preferable to TFP for some analytical purposes. For example, an environmental economist or policymaker might be more interested in trends in the energy intensity of production – which measures of energy productivity provide – than in trends in TFP. Our empirical overview of productivity trends in natural resource industries, presented in Section III, is meant to illustrate these points.

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Alexander Murray
and Andrew Sharpe

Smart Prosperity Institute

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