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Natural Capital and Technological Change: Impacts on Productivity Growth and Natural Resource and Environmental Sustainability

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Introduction: The Role of Natural and Environmental Resources in the Canadian Economy

The economy's goods and services are produced with factor inputs; traditionally identified as land, labour, and capital. Land is a proxy for the stocks of natural resources – land and soils, timber, minerals, energy, water and the capacity of the natural environment to absorb or neutralize the waste products of production and consumption. Economic modeling in much of the 20th century typically focused on the roles of labour and capital, implicitly assuming that natural and environmental resources were so abundant that they could be treated as 'free' goods. Of course, most economists recognized that natural resources used as inputs were not free; capital and labour had to be used to extract or harvest them, but because of the relative abundance of natural resources, they were routinely ignored in productivity studies and other aggregate analyses of the economy. It was only when natural and environmental resources were particularly scarce, for example, during the 'energy crisis' of the 1970s when petroleum prices skyrocketed, that natural resources entered into estimations of production functions and productivity.[1] The late 1960s and early 1970s also ushered in awareness of increasing scarcity of environmental resources because pollution levels began to have noticeable impacts on human and ecosystem health.

The stock of natural resources is known as natural capital – capital in the sense that resources are an asset that yields services over time, but can also be depreciated. Depreciation of natural capital arises from depletion of natural and environmental resource stocks. Measurement of Canada's natural capital has focused thus far on stocks of land, energy, mineral, and timber reserves.[2] Measurement of the natural capital embodied in environmental resources is very difficult to conceptualize, let alone measure. However, even for the resources whose natural capital is more readily measurable, there is still very little in the way of empirical estimation of natural capital's contribution to productivity. Research on on how changes in the stocks of natural resources affects the

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[1] Examples are the so-called KLEM – capital, labour, energy, and materials production and cost functions that were estimated in the 1980s.

[2] Some renewable resource stocks, namely fish and other wildlife, are difficult to observe in nature, for example, locating a migratory fish stock in the oceans. Natural capital data for these resources is therefore very slim and limited to studies of individual species. Aggregate data is not available.

sustainability of resource extraction or harvesting and ultimately, that of the economy is limited, but growing.[3]

Sustainability, broadly defined is the ability of the economy to maintain a flow of production necessary to ensure non-decreasing consumption per capita indefinitely. To sustain production, the economy needs a constant supply of the inputs that are essential in the sense that without these inputs, no output could be produced. The relationship between natural capital and sustainable output then depends on whether natural capital is essential or not, i.e., what are the substitution possibilities between factor inputs. Some forms of natural capital are clearly essential - water and our atmosphere for example. If the protective stratospheric ozone layer is lost, the earth's temperatures would fall below those compatible with survival of humans and most other life forms. Other types of natural capital - specific nonrenewable or renewable resources (oil, timber), and even some of the waste assimilation processes of the natural environment may not be essential. Natural gas, oil products extracted from tar sands, or biofuels can be substitutes for conventional oil is most uses. It is energy that is the key input in this case, not the specific type of energy input that is essential for production. Water and sewage treatment plants (reproduced capital) can substitute for the waste absorption capacity of rivers and lakes.

The concepts of weak and strong sustainability reflect how essential natural capital is to the economy and environment. Weak sustainability requires the maintenance of an aggregate stock of capital (natural, human, and reproduced) at a level necessary to ensure indefinite production. All of the forms of capital aggregated under weak sustainability must therefore be perfectly substitutable for each other. Strong sustainability says that specific forms of natural capital are essential (they do not have substitutes) and stocks of these resources must remain intact over time to ensure continued production. The challenges are to discover what forms of natural capital are essential and how to sustain stock sizes needed to ensure non-decreasing production, consumption, and hence, human survival. We do not have good estimates of how much natural capital we need. Our knowledge is particularly weak when it comes to understanding the complex roles of ecosystems in sustaining things like the hydrological cycle, climate, biodiversity, soil productivity, and other natural processes.

The goals of this paper are necessarily to explore potential relationships between natural capital, productivity, and sustainability. Two questions are posed. First, how important is natural capital in sustaining production in the Canadian economy over time? Second, has the role of natural capital changed over time due to two factors: its depletion

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[3] Economic analysis of sustainability dates back to classic pieces such as Jevon's concern about using up coal resources in 18th century England, and Malthus' fears about the limits to food production. The 20th century literature emanates from pieces such as Hotelling's theoretical model of nonrenewable resource production (Hotelling, 1931), the open access renewable resource model (e.g., Gordon, 1954), Barnett and Morse's work (1963, 1979) on scarcity and growth, the Club of Rome's limits to growth (Meadows et al., 1972), and much theoretical literature spawned by these works. Economists have certainly been concerned about the contribution of natural capital to sustainability for centuries. But what is sparse is the systematic inclusion of natural capital into economic analyses of productivity growth, and in turn, linking productivity growth to sustainability.

or degradation and technological change? The approach is analysis of available data to help provide an overview and suggested interpretation of what are very complex relationships.

Long-Run Trends for Canadian Natural Resource Capital

Figures 1 and 2 illustrate trends in output from natural resource industries and natural resource reserves – a measure of natural capital for timber, oil, natural gas, and coal over the past 40 years.[4] Three patterns are apparent. The stocks of natural capital are either falling (timber and oil), an inverted U-shape (gas), or rising in a nonlinear fashion (coal) where the rate of increase has slowed in recent years. However, in all cases, production of these resources has been rising over time. Thus, the declining stocks of timber and oil do not appear to be restraining production. The scale given in Figure 2 is indicative of why: natural resource reserves are still many orders of magnitude larger than annual production. In all cases, Canada also imports, as well as exports these natural resources.

Insert Figures 1 and 2 near here.

Measures of reserves of natural resources are sensitive to current prices in that they measure stocks economically recoverable, i.e., extractable at the prevailing prices. Many natural resources have seen generally falling real prices over the past 20 years.[5] Long-run real prices of oil and gas have had trended downward from 1981 to 1998, as shown in Figure 3. Figure 4 illustrates that the implicit value of timber harvests, while cyclical, is generally declining over the period 1961-1998. What this data suggests is that while oil, gas, and timber stocks have been declining over time, they do not appear to be inhibiting the flow of output, i.e., harvested timber and extracted energy resources. None of the resources examined are becoming more scarce in an economic sense because their prices over the long term have not been rising.[6] This does not mean that declining reserves will not ultimately lead to rising prices, because prices depend not only on Canadian supply, but world supply, and of course, the demand for these resources. Canadian depletion of many natural resources may simply be too insignificant to affect world prices. This is where the distinction between weak and strong sustainability is important. If these forms of natural capital have substitutes in the form of natural capital from other sources, labour, or reproduced capital, the decline in their stocks will not signal any economic dislocation.

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[4] Reserves data are the most readily available estimates of natural capital. There are different ways of estimating reserves, each having advantages and disadvantages. The estimates presented in this paper are thus illustrative, not definitive. Production of coal is not shown on Figure 2 because it would not show up on the scale presented. Estimates of other forms of natural capital – soil depth, arable land, fish stocks are less readily available and hence, not presented here.

[5] This is the case for oil and gas, many minerals, timber (although it is cyclical), but not for many types of fish.

[6] A better measure of the scarcity of new stocks of a natural resource is the marginal cost of discovering new reserves in the case on nonrenewable resources or the marginal cost of growing an incremental stock of renewable resources. This sort of data is not readily available in an aggregate measure.

Declining natural resource prices may also be due to other factors. The composition of Canadian output may be changing over time. Technological changes, innovations, and rising labour productivity (e.g., due to increases in human capital) can reduce the amount of natural capital required per unit output. These factors will be considered below. Two important caveats in this discussion are that first, declining stocks of renewable resources may have an impact on environmental capital such as biodiversity and ecosystem integrity, not to mention quality of life. Second, the discussion thus far has focused on natural rather than environmental resources because of the data limitations for environmental resources. Environmental resources are addressed briefly at the end of the paper.

Insert Figures 3 and 4 near here.

One can get a rough picture of the relative contribution of natural resource capital to total resource output by examining changes in real output over time. Table 1 shows that output has risen for all resource sectors except for fishing and trapping (from 1981 to 1997). Real GDP growth for all Canadian industries has risen at an annual average rate of 6.5 percent from 1961 to 1980 and 2.6 percent from 1981 to 1997. In the latter period, only one industry – coal exceeds the growth in real output of the aggregate economy.[7] The other sectors growing more slowly. This suggests that these resource sectors represent a smaller share of the value of total output over time. This is explained at least in part, by the declining real prices of many resources. But, one might also infer that there has been a reduction in the essentialness of natural capital from these sectors; or put another way, the economy may be developing substitutes for some of its domestic natural capital. The data suggests that some of the energy sectors are growing more quickly than the aggregate economy.[8] This suggests that energy's output share in the value of total output may be rising and runs counter to the argument that natural capital may be becoming less important in the aggregate economy over time. Recall from Figure 3 that the real prices of oil and gas fell from 1981 to 1997. The relative importance of energy may thus be even greater than suggested by the trends in real output growth.[9] Figure 5 examine the ratios of energy output in physical units for oil, gas, and coal to the economy's GDP (in constant dollars). The share of output of coal is rising, natural gas U-shaped and rising since the late 1980s; oil output relative to GDP is falling. These trends may well have implications for sustainability, especially when one considers environmental capital. The energy sector is more pollution intensive than other industries. The fishing and trapping industry is a special case; all the data and

[7] Oil and gas and agriculture have average annual growth rates that are just below that of the aggregate economy. One should also be cautious about using specific end points for computing average anuual growth rates.

[8] Coal is used to generate electricity and as an input into steel production.

[9] Total energy consumption in proportion to constant dollar GDP fell by 5.9 percent from 1981 to 1997. The share discussed above is for production of energy inputs and hence also includes resource exports. For data on energy consumption, see Environment Canada, State of the Environment Indicators at: www.ec.gc.ca/ind/English/Tables/ectb01_e.cfm.

information available about fish stocks points to a significant decline in natural capital – major reductions in fish stocks due to harvesting and natural conditions.[10]

Insert Figure 5 near here

Table 1 also shows that unit labour costs (in constant dollars) have fallen over the past 17 years for three of the five industries shown, but risen quite substantially in fishing and trapping. Apart from fishing, all the sectors with declining reserves also have declining (or relatively constant for oil and gas) real labour costs. This potentially reflects two factors: technological improvements in both physical and human capital have offset what would otherwise be higher production costs due to depletion, and substitutes for these forms of natural capital have been found. It appears thus far, that only in the case of fishing does the depletion of natural capital appears to have contributed to an increase in production costs, in this case, the cost of labour per unit output.

Table 1: Average Annual Percentage Changes in Real Output and Unit Labour Costs

	% Change in Real Output		**% Change in Unit Labour Costs**
	1961-1980	**1981-1997**	**1981-1997**
Agriculture	1.2	2.5	-4.0
Fishing & Trapping	0.4	-0.9	7.8
Logging & Forestry	1.7	0.8	-0.1
Mining	1.3	1.5	-2.2
Coal	1.8	4.6	NA
Oil & Natural Gas	2.4	2.5	0.8

Source: Statistics Canada, Indexes of Real Gross Domestic Product by Industry, Unit Labour Cost by Industry, annual dollars converted to constant dollars by GDP deflator, 1997=100.

Finally, note that all the data presented in this paper is aggregated to the national level. Resource stocks, and the importance of natural resources in provincial GDP vary across the country, e.g., British Columbia and Alberta are much more resource-intensive provinces compared to Ontario or Quebec. As well, changes in resource stocks may differ across the country, e.g., timber reserves may be falling more quickly in B.C. than in Quebec. Because of this variability, should one examine natural capital and sustainability at the natural or regional levels? This paper will focus on the national level because

[10] The cod fishery is an example of how excessive harvesting has depleted the stock to the point where virtually no commercial harvests are viable and the stocks themselves may be irreversibly exhausted. Stocks of several Pacific salmon species also have declined significantly in recent years due to changes in water temperature, migration patterns, harvesting, disease, and other factors that are not all clearly understood.

natural resource capital from one part of the country can be substituted for that in another. It may be even argued that even the national level is too limited because natural resources from other countries may be substituted for declining natural capital stocks in Canada. This does not hold for environmental resources – one cannot substitute air quality in Regina for that in Toronto.

Natural Capital and Productivity Growth

Productivity growth may be linked to sustainability because it indicates scope for improvements in a country's living standards that are in principle, sustainable by technological advances.[11] If there is productivity growth, particularly in the natural resource sectors, then despite what is happening to natural capital stocks, the economy may be able to sustain natural resource production over time. Supplies of extracted or harvested natural resources will be non-decreasing and hence, output of other goods and services using these inputs can be sustained. Two measures of productivity growth are commonly used to gauge the ability of the economy to produce goods and services over time: labour productivity and multi-factor productivity (MFP). Labour productivity tells how much is produced per worker and hence, the real income available to Canadians. In this sense, it links well with sustainability by showing how much sustainable consumption is possible. Multi-factor productivity is used as a measure of technological change. It is measured as the growth rate of output minus the growth rate of the inputs weighted by their input shares, where the two inputs commonly included are capital and labour. The 'unexplained' portion of output growth is thus interpreted as technological change. But, natural capital is also an input into the production of goods and services. However, natural capital is difficult to include, even if we could measure it, because we do not know its input share without estimating production functions; it is thus part of the residual. There are a few estimates of the contribution of natural capital to productivity growth for individual industries.[12] Labour productivity, then MFP are now examined for Canada's natural resource sectors.

Labour Productivity in Natural Resource Industries

Labour productivity growth rates in Canada and the United States for the total economy versus the primary sectors are shown in Table 2 for several time periods starting in 1989. [13] One can draw several conclusions from this table. Productivity growth in the primary sectors, as a whole, significantly exceeds that of the whole economy. While the

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[11] See Andrew Sharpe's paper (2002) in this volume for a more in depth discussion of measures of productivity and what they mean for the economy and sustainability. Also see Sharpe (2001) and Smith and Simard (2001).

[12] See Squires (1992), Repetto (1996) and Swinand (1999). These papers will be discussed in more detail below.

[13] All labour productivity figures for Canada represent the entire primary natural resource industry. This means they will include both production and non-production workers as well as those in both the initial harvesting or extraction plus some processing (e.g., sawmilling and pulp production for forestry, on mine site concentrating of ores, and similarly for other industries). Separating out the primary harvesting/extraction activities on their own would have to be done by province and most likely would involve micro-level studies.

growth rates for the primary sector dipped a bit during the late 1990s, it recovered almost back to the levels seen in 1989-95 and remains more than twice as high as those in the economy as a whole. Secondly, while the U.S. has higher productivity growth overall than Canada, the primary sector in Canada is consistently at least twice as productive as that in the United States. This overall picture supports a finding of sustainable consumption and is consistent with finding weak sustainability of natural resource capital from the primary sector. However, these inferences are based on aggregate data that obscures many different patterns amongst the primary industries.

Table 2: Labour Productivity Growth* – Total Economy versus Primary Sectors, Canada and the United States

	Total Economy		Primary Sector	
	Canada	United States	Canada	United States
1989-95	1.0%	1.2%	3.1%	1.5%
1995-00	1.6	2.4	2.5	1.1
1989-00	1.2	1.7	2.9	1.3

* Real GDP per worker, average annual percent rate of change

Source: Rao and Tang (2001), Table 2.

Table 2 breaks down the primary sector in Canada into separate industries and provides average annual rates of growth in labour productivity over the four decades starting in 1961. There is no uniform pattern. While most resource industries have had a slowdown in growth (and even periods of negative growth) since the 1970s, oil and gas exhibits its highest labour productivity growth in the 1990s. But even these average rates expressed per decade do not accurately show the longer time trends in each industry. For example, the fishing and trapping industry recovered somewhat in the 1990s from two decades of decline. However, the index of labour productivity in 2000 is far below that in the late 1960s.

Table 3: Average Annual Labour Productivity Growth in Resource Industries, Canada Aggregate

	1961-70	1971-80	1981-90	1991-97	1991-2000
Agriculture	2.2%	1.7%	2.6 %	0.1%	4.3%
Fishing & Trapping	6.0	-3.3	-3.0	4.5	2.6
Forestry	1.5	1.3	2.0	1.9	1.8
Mining	1.7	0.7	4.0	- 0.1	NA
Coal	3.2	1.9	7.0	5.4	NA
Oil & Gas	0.5	- 9.9	- 0.4	5.2	NA

Source: Statistics Canada, Indexes of Real GDP per Hour Worked, 1961-1997, 1961-2000.

Labour productivity over the past 40 years for the renewable and nonrenewable resource industries is shown in Figures 6 and 7. Figure 6 illustrates the diversity among the renewable resources. Labour productivity has been generally rising for agriculture[14] and forestry, but declining since the late 1970s for fishing and trapping. Over the entire period, labour productivity in agriculture grew by 313 percent, forestry by 158 percent, while fishing and trapping declined by 0.2%. Recall from the previous section that the stock of forest natural capital has been declining over the past 40 years, as have most fish stocks, but their labour productivity trends are quite different. There are many possible explanations for the difference in the two sectors. The role of technological change is examined in the next two sections. Responses of each industry to changing prices may also play a role. Industries with declining real prices over significant parts of the time series (timber and agriculture) may restructure and consolidate their enterprises, thus improving labour productivity. But changes in natural capital may also be playing a role. Natural capital in fisheries may have crossed a threshold below which sustainable production from that sector is not possible, despite trying to substitute other inputs for the declining stock of natural capital. Falling labour productivity is consistent with this argument. Theoretical models of open access and imperfectly regulated fisheries have predicted for many years that harvests which exceed the sustainable yield from the fishery will ultimately exhaust the fishery. Natural capital is clearly essential for this industry. One cannot substitute labour and capital indefinitely to sustain the harvest.

Insert Figure 6 near here

The decline in forest stocks reflects harvesting of old growth timber and its replacement with lower yielding second growth. While the total stock has declined, it has not affected labour productivity adversely because annual harvests are still taking only a small percentage of the total stock of timber in each year. Annual harvests have risen from 0.6 to 1.4 percent of the timber stock.[15] At these rates, even if there were no growth in the forest capital, it would take over 200 years to deplete the stock. For agriculture, data is available for measures of natural capital for 1981 and 1996. Total area in farms and land in crops has risen by 3.3 and 12.8 percent respectively, while that in pasture and summerfallow has fallen by 1.3 and 35.5 percent. This data suggests no clear picture with regard to the impact of changes in agricultural capital on labour productivity in this sector.[16]

Insert Figure 7 near here.

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[14] One must be cautious with labour productivity measures for agriculture because wage income is low relative to total income. Labour productivity overstates productivity in this sector. In all these estimates of labour productivity, labour is measured as hours worked.

[15] Timber stocks have declined from 14.7 to 12.9 billion cubic metres, while harvests have risen from 92.2 to 181.2 million cubic metres.

[16] It is beyond the scope of this paper to examine agriculture in detail. There are number of estimates of agricultural production functions and the role of natural capital in agriculture may be better gleaned from this work.

Labour productivity for nonrenewable resource industries is illustrated in Figure 7. For coal and mining, labour productivity is generally rising throughout the period, while for oil and natural gas, there is a more complex relationship, where productivity declines from the mid-1970s to early 1980s, then rises thereafter at a rate roughly comparable to mining (until the most recent years).[17] During the 1970s and early 1980s, exploration for new reserves was driven by increases in the real price of energy and by regulation that required a minimum ratio of reserves to extraction to obtain export licenses. This led to large increases in labour (and capital) with more extensive and intensive drilling, but little in the way of incremental output. Recall from Figure 2 that reserves of oil were falling. This decline in natural capital would also help explain the falling labour productivity. Declining stocks of natural capital may have played a role for oil, but not for natural gas. Gas reserves were rising over this period. The data from the mid-1980s indicates that once the reserve ratio regulation was lifted, exploration activity was based on expected profits, falling when energy prices decreased. Labour productivity has been rising since the mid-1980s. Technological change is now playing a bigger role (as will be discussed below). The story for coal is similar to that of forests where the reserves of natural capital are enormous relative to current extraction. Mining is an aggregate that obscures developments going on with individual minerals and hence, it is difficult to explain trends in labour productivity. Reserves (and prices) have declined for some, but not all minerals. But in aggregate, labour productivity is rising, again signaling that there is no immediate cause for concern about sustainability.

How does labour productivity in Canada's resource industries compare to that in the United States? Parry (1997) looks at coal, petroleum, logging, and copper. His estimates of labour productivity in the U.S. yield paths over time similar to those in Canada.

Multi-factor Productivity in Natural Resource Industries

Figures 8 and 9 present MFP for renewable and nonrenewable resource industries compared to that for all industries. As noted above, MFP gives us an estimate of the combined effects of technological change and changes in natural capital over time (if it is an excluded input). In Figure 8, note that of the renewable resource industries, only agriculture has a generally rising trend over time and a rate of growth that exceeds that of all industries combined. Forestry and fishing are somewhat more cyclical, but trending downward with levels falling below that of all industries after the early 1990s, with fisheries falling below the level of the 1984 base year. The trends are quite different in the nonrenewable sectors. Here, all the industries have levels that lie above that of all industries after the early 1990s, and rising trends from 1984 to 1993, except for coal which rises throughout the period with an acceleration in productivity growth after the early 1990s. These estimates suggest very different roles of technological change and/or changes in natural capital in the renewable versus nonrenewable sectors. This is explored more fully below for the energy sector versus forestry.

[17] It is unfortunate that oil and gas are aggregated in Statistics Canada's series on labour productivity because as Figure 2 illustrates, their stocks of natural capital do not always move in the same direction.

Insert Figures 8 and 9 near here.

While labour productivity trends in Canada are similar to that of the United States, MFP growth is somewhat different. Table 4 illustrates that Canada's MFP average annual growth was considerably greater than that of the United States over this period.

Table 4: Average Annual Growth in Multi-factor Productivity, 1985-94

	Coal	**Petroleum***	**Logging**
Canada	11.3%	5.8%	-1.8%
United States	1.4	3.7	-2.1

Notes: * Includes natural gas in Canada
Sources: Parry (1997, from Figure 5), Centre for the Study of Living Standards as cited in Natural Resources Canada, *Energy in Canada 2000*, Total Factor Productivity Indices.

As before, one must be careful with picking a specific time interval if the trend has been cyclical, but the data for the ten-year period indicates that Canadian resource industries are doing better than their counterparts in the United States. Is this due to greater technological change in Canada than in the U.S.? It is doubtful because the two economies are so closely linked and one would think that technological change would readily flow between the countries. Because natural capital is omitted from the MFP calculation, an alternative, and more plausible explanation might be that the U.S. had a greater impact of declining natural capital in these sectors than in Canada. An examination of this possibility is beyond the scope of this paper, but warrants investigation.

It is generally expected that the growth rate of MFP will be less than that of labour productivity because the growth rate of the capital stock (or capital plus intermediate inputs) is typically greater than that of employment, i.e., capital-labour ratios tend to be rising over time. If we look at average annual growth rates in the two measures of productivity for Canadian resource industries we find that they are highly variable year-to-year and that in a number of years, MFP exceeds labour productivity. This variability suggests that by omitting natural capital as an input in MFP measurement (i.e., it then appears as technological change), the estimates are skewed in an unexpected direction. This skewness may arise because the MFP estimates do not distinguish between impacts of changes in natural capital from technological change. If natural capital is rising over time, traditional MFP estimates will overstate technological change and vice versa for a given level of output growth. If traditional MFP is still rising while natural capital is declining, then sustainability seems likely because technological change and substitution of other inputs is occurring. But when MFP declines consistently over time, concern about sustainability is warranted. Timber is used as an example to try to determine whether the lack of explicit measurement of natural capital inputs (in the form of changing timber stocks) in MFP may explain divergences between MFP and labour productivity and growth rates of MFP.[18]

Insert Figure 10 near here

In the forestry and logging industry, on average over the period from 1984 to 1997, labour productivity fell at a 0.3% average annual rate, while MFP rose by 0.3% per year. Figure 10 shows that the MFP growth rate exceeded that of labour productivity in 8 of the 14 years, sometimes substantially so. However, the data is highly variable year-to-year, indicating there is unlikely to be any stable relationship between MFP and changing input ratios over time. Figure 11 tries to dig a bit deeper to see if it is changes in natural capital that might be contributing to higher levels of MFP growth. It shows the ratio of natural capital (timber stocks) to labour to see if there has been any trend over time in this ratio. Recall from Figure 1 than natural capital stocks of timber have been declining over time. If labour is being substituted for capital and the natural capital to labour ratio is therefore declining, then this could explain lower rates of labour productivity growth than MFP because labour and natural capital are not good substitutes in this industry and indicate caution about long-term sustainability.[19] The labour deepening with a declining resource stock may yield lower rates of output growth in the future. There is however, no discernable trend exhibited in Figure 11.

Insert Figure 11 near here

Another way to examine the possible role of natural capital is to see if it acts as a constraint on trends in MFP, measured using the traditional inputs of capital and labour. MFP, in both level and annual percentage change, is regressed on natural capital levels and annual percentage change to see if there is a significant relationship. There is not. However, the time series is extremely short and timber stocks (as noted above) are still quite large relative to annual production. A long-term relationship may be developing, but it is too early to discern this.

A better candidate for studying the relationship between MFP and labour productivity would be the fishing industry. However, because data on natural capital is not available at any sort of aggregate level in Canada, this is not possible. A study done on several fisheries in the United States shows that omitting natural capital from productivity measurement does bias the estimates. Squires (1992) measures total factor productivity (TFP) in the open access Pacific coast trawl fishery, explicitly accounting for changes in the abundance of fish stocks. TFP properly measured is "the residual after allocating the growth rate of output among changes in variable inputs, capital, and resource abundance" (Squires, 1992, p. 225). Squires compares the conventional

[18] Coal also has MFP growth in excess of labour productivity growth for the ten-year period from the mid-1980s to mid-1990s. It's reserves also declined over this period, after rising substantially in the early 1980s.

[19] One should also look at natural capital to reproduced capital ratios and capital-labour ratios to get a more complete picture.

measure of TFP with that inclusive of natural capital. He finds that in years where fish biomass is declining, conventional TFP understates 'true' TFP that includes the resource stock and analogously, for years when biomass is rising, conventional TFP overstates true productivity growth. This is because in abundant years, it is easier to harvest fish and by not including the resource stock, it looks like technological change is the contributing factor to the increased outputs, not the increase in the resource stock. Overall in his time series, true productivity growth on average is about half that of measured TFP. Changes in the resource stock (and other variables such as capacity utilization and the catchability of the fish stock) were responsible for a significant portion of the measured productivity growth. Proper accounting for changes in natural capital is thus important to provide a more accurate picture of productivity growth and sustainability.

Links between Natural Capital, Technological Change, and Sustainability of Natural Resources

Multi-factor productivity growth captures both changes in natural capital and technological change, and as we saw from above, it is important to try to estimate natural capital inputs to accurately measure productivity growth. But these two components of productivity growth are also not independent of one another. For example, depletion of natural capital may stimulate investment in research and development to increase the stock size. For nonrenewable resources, better exploration techniques may result in more discoveries of viable reserves. With renewable resources, genetic and selective breeding techniques may increase biomass (e.g, timber volume, fish weight and size, crop yields). New technologies for extraction or harvesting may yield higher recovery of a given stock of total reserves. There are many examples: offsetting the natural decline in pressure for oil and gas deposits; finding more fish in the oceans due to satellite mapping of fish stocks; or recovering more usable timber from a given tree due to better harvesting and sawmilling technology.

A second factor may be regulation. This is particularly relevant for environmental resources. Government policies that require producers and consumers to reduce waste emissions may induce technological changes that reduce the amount of emissions created per unit output, thus increasing the stock of environmental capital. This can be accomplished by, for example, substituting less polluting inputs for those that release more wastes, or by introducing technologies that turn what were waste products into inputs that can be used on site or by other businesses. Regulation also plays a role with natural resources. For example, regulation of open access fisheries may induce firms to manage aquatic stocks in a more sustainable manner.

Innovation takes time both for discovering appropriate technologies and for diffusion into a particular sector from other sectors or other countries. The innovations we see today may be due to changes in natural capital that occurred some time ago, or have occurred in different countries and have spilled over into Canada. Thresholds may have to be crossed wherein the decline in natural capital (relative to production) reaches a point where it pays to look for ways to augment the stock or recover more of the extracted resource per unit of stock. The precise relationships are difficult to discover. Below, a number of examples of technological change in natural resource industries are provided to illustrate some of the factors responsible.

Examples of Technological Change in Natural Resource Industries

Simpson (1999) and the papers within that volume examine technological changes and innovations in four U.S. natural resource industries: coal, petroleum, copper, and forestry. The lessons learned from this study are applicable to the Canadian counterparts. However, the technology transfer from the U.S. to Canada is not complete, as examples from the energy sector and forestry will illustrate. A snapshot of each industry is provided to help 'explain' changes in productivity in these industries over the past 40 years and to highlight the role played by depletion of the natural capital and environmental regulations.

Coal

Coal is an 'old' natural resource. It has been used as an energy source for hundreds of years and in steel making. Coal is a significant input into electricity generation in the United States, less so in Canada. As Figure 2 shows, reserves of coal in Canada (and also worldwide) are enormous; there is no fear of depletion for the foreseeable future due to exhaustion of the natural capital stock.[20] Natural capital stocks are thus not a constraint on production of coal. Labour productivity and MFP growth rates for coal have been very high in some time periods, among the highest of all the natural resources (as illustrated in Tables 2 and 3 and Figures 6 and 8). In the U.S., labour productivity growth averaged 4.1 percent over the period 1950-1995, compared to 3.1 percent in Canada from 1961-1995.[21] Thus, technological changes in the United States have likely spilled over into Canada. The industry has had a large decrease in labour intensity due to the adoption of new technologies.[22] For example, surface mining deployed ever larger and more sophisticated equipment to extract ore (e.g., large electrified draglines), while longwalling mining techniques improved productivity in underground mines. Use of remote control computer processes and other information technology innovations pervade the industry. The capital intensity of the industry increased considerably over the past 40 years, but MFP also increased, indicating continued and strong technological change. However, recall that if coal reserves are growing, MFP measures may be overstating technological change.

Innovation has also been stimulated by environmental and health and safety regulations in the industry that were introduced in the 1970s. For example, the Clean Air Act in the United States mandated reductions in sulphur emissions from fossil fuel

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[20] Coal may be 'economically depleted' if, due to environmental considerations and the development of less pollution-intensive energy sources, demand for it diminishes over time. It is possible that demand for coal as an energy input may effectively go to zero long before the stocks are depleted. If so, coal is clearly not an essential natural resource.

[21] If Canadian labour productivity data were available back to 1950, Canadian numbers would probably be at least as large as those in the United States.

[22] Information about coal is taken from Darmstadter (1997).

combustion in electric power plants. New technologies to reduce sulphur were developed in response. The regulations also induced substitution of less sulphur-intensive coal (from the western U.S.) for the high-sulphur coal of the east. This led to improvements in rail transportation that also increased productivity. The impact of these regulations on productivity is instructive. Labour productivity in the U.S. coal industry fell during the 1970s by 1.9 percent. The regulations, along with periods of major labour unrest and entry of inefficient producers responding to high energy prices in the 1970s, were deemed responsible for decline in productivity. But labour productivity growth from 1980 to 1995 was 6.6 percent on average per year, a growth rate significantly above that of the pre-regulatory period (e.g., from 1960-69 it was 4 percent). Improvements in labour relations, falling coal prices, and increases in efficiency and new marketable by-products (sulphur and methane) recovered from pollution abatement technologies are the reasons given for the boost to productivity. In Canada, concerns over acid precipitation led to regulations requiring a 50 percent reduction in sulphur emissions from fossil fuel combustion in eastern Canada. Canadian coal users (e.g., Ontario Hydro, now Ontario Power Generation) adopted the new pollution abatement technologies. Coal is thus an example where regulation-induced technological change is strong and has been a major factor in productivity growth, once the adjustment to capital acquisition and new technologies occurred.

Petroleum

Unlike coal, with its vast stocks of natural capital, oil and gas reserves have been declining over time with Canadian conventional oil reserves in 1998 approximately half what they were in 1970 (see Figure 2). Incentives for development of new technologies in this sector are therefore more likely to be based on the depletion of reserves than was the case with coal. Innovations that improve the probability of discovering new reserves of oil and gas, or allow for greater recovery of oil and gas from existing reserves will help keep costs of extraction from rising as quickly as the stocks of reserves are drawn down. Recall as well that real prices of petroleum resources have fallen, thus intensifying the need to reduce costs to help the North American industry stay viable. Given a world price that governs supply and demand, North American producers compete with lower-cost suppliers such as those in the Middle East. Bohi (1998) identifies three major innovations: three-dimensional seismology, horizontal and deepwater drilling that have lowered the costs of exploration and development of deposits. Other innovations improve recovery of oil from existing wells; these involve methods of replacing the losses in natural pressure, allowing increases in total reserves extracted from a given deposit. Environmental regulations, while inducing some technological change, are not felt to be as important a factor in this sector as for coal (Simpson ,1999).

Figure 7 showed the fall in labour productivity in Canada from the 1970s to mid-1980s. This also occurred in the United States, even though they did not have the same regulatory environment as did Canada. Bohi's explanation is that there was a large reduction in the number of wells drilled during that period – by the 1990s, drilling was one-half that being undertaken prior to 1973, combined with no reduction in labour inputs over this period. In Canada, oil and gas exploration declined by 60 percent from 1983 to

1995, and private research and development expenditures (in constant dollars) have been essentially flat from the 1980s to late 1990s.[23] Government investment in energy R&D declined by 75 percent from 1984 to 2000. But while R&D investment in nonrenewable energy resources has declining, there has been a steady increase in electric utility R&D (2 percent per year), with a portion devoted to renewable energy resources. Canada is also a world leader in fuel cell technology. While nonrenewable fossil fuels still represent a major input in energy use, the falling budgets for R&D suggest that both the private and public sector view this as a resource declining in importance as an input to energy production. Unless these decision makers are misguided, it suggests that petroleum resources are not viewed as essential - the concept of weak sustainability applies as substitutes begin to replace nonrenewable fuels.

Copper

Copper mining is almost as old as human civilization. The industry in North America dates back to the 19th century. Although some discoveries have been made in the past 40 years, reserves in Canada and the U.S. were generally depleted by the 1970s to the point where the industry could no longer compete with lower cost mines in other parts of the world. Copper prices remained low due to sufficient worldwide supplies and substitution away from copper inputs (e.g., fibre optic cable rather than copper wire). In mining, it is both the quantity of natural capital and quality that affects costs of extraction. The 'best' ore bodies are typically extracted first. As depletion occurs, labour (and MFP) productivity should decline because poorer quality deposits either reduce output per unit input or require more inputs per unit output. The situation facing U.S. and Canadian producers was to either find innovative ways of recovering copper at costs allowing them to continue to produce, or shut down. There was essentially no productivity growth from 1960 to 1975 in the U.S. copper industry (Tilton and Lansberg, 1997).[24]

Major innovations did occur in this industry in response to depletion and no productivity growth. A notable example is the recovery of copper from mine tailings using a chemical process that required the development of new solvents.[25] Wastes are literally 're-mined' to extract copper uncovered using older, less efficient technologies, essentially allowing a higher percentage of metal to be ultimately recovered from an orebody. The process cut the tonnes of waste per tonne of ore mined by over 35 percent, and output in 1995 was 21 percent above its level in 1970, and 72 percent above its 1985 level. Labour productivity growth reflects this technological 'boost', rising 50 percent from 1980 to 1986.[26] Re-mining has a limited life, and these deposits will be exhausted. Productivity growth in the 1990s, while still much higher than the 1960s to 1970s, has begun to flatten. Copper illustrates how technological change can extend the life of a

[23] See United States, Department of Energy (2000).
[24] Tilton and Landsberg (1997) are the source for all the information about the U.S. copper industry.
[25] This is called solvent extraction electrowinning. Not all mines adopted this technology. Some had closed permanently and others did not have favourable conditions for use of the technology.
[26] The total labour force also fell sharply after the 1970s due to mine closures and capital deepening. Real wages also fell due to removal of unions at some mines.

nonrenewable natural resource. Copper is not an essential resource for most of its uses. One therefore expects to see productivity begin to fall unless further technological change occurs.

Forestry

Forests are a renewable resource, but like the nonrenewable commodities discussed above, their natural capital can be depleted. This can arise because old growth forests often have far more wood volume per hectare than the secondary forests that replace them (whether they are planted or natural regeneration is used). Soil fertility is the depletable resource in this case. Unless forest companies invest in inputs to improve fertility, productivity of the forest land will decline over time. Other factors are insufficient reforestation of timber lands. This can occur when property rights to forest land are insecure; harvesters have no guarantee that a tree planted today will be available for harvest by them in 30 to 80 years. Long growing periods for this 'crop' clearly exacerbate the problem. Property rights may be insecure even in North America because of inconsistent government policy, e.g., changing leasehold arrangements or bidding policies for timber harvesting rights on crown lands. In the 19th and early parts of the 20th century, many forests were essentially open access, allowing harvesters to 'cut and run'. By the 21st century, the timber industry can be characterized as having depleted much of its high quality timber. Most of the industry is harvesting secondary growth, and for the segment of the industry still cutting old growth, the sites are increasingly inaccessible. As shown in Figure 1, the stock of timber has steadily declined in Canada over the past 40 years. Other factors contributing to the decline in natural capital include environmental regulations, land use restrictions, and conversion of forested lands to other uses such as agriculture, residential areas, and protected sites. This removal of land from timber production represents an interesting tradeoff. The decrease in the supply of timber lands reduces natural capital which could, in turn, lower productivity due to less input and, potentially, higher prices for the remaining land. On the other hand, greater scarcity of natural capital could stimulate R&D on intensive forestry technologies.

Figures in this paper[27] showed that the Canadian forest industry is characterized by steadily declining natural capital (timber stocks), generally rising labour productivity, and from the period from 1986 to 1994, declining MFP. A closer look at the B.C. forest industry illustrates factors responsible for productivity changes in this industry and the potential for sustainable timber production.[28] Over the period 1970 to 1981, labour productivity in the B.C. forest industry was relatively flat; it rose by over 60 percent from 1981 to 1987, then fell by about 9 percent from 1987 to 1992. Unit labour costs during the 1970s rose by 144 percent, reflecting a period of significant labour unrest, but growth in labour costs then sharply declined after 1981 to about 1 percent per year. Despite the growth in labour costs until the 1980s, net logging costs[29] were essentially flat from 1975 to 1993. What occurred over the period since the 1970s was the introduction of labour-saving logging innovations that held down total costs. An example is a new form of

[27] See Figures 1, 6, 8, 10, and 11.
[28] This information is taken from Sedjo (1997).
[29] These are total costs net of stumpage fees, royalties, depreciation, and a rate of return on investment.

attaching felled trees to cables to remove them from the site (grappling). Other innovations in sawmilling technology, for example, use of computers to recover more usable wood per tree, have also been adopted in part of the industry. In the 1990s, provincial regulation of forest practices imposed new policies such as stricter standards on logging road construction and maintenance, done ostensibly for environmental protection. These regulations limit the use of the labour-saving grappling technology, hence increasing logging costs. Other regulations that restrict harvests on sites adjacent to recently cut areas may also lead to extensive logging in more remote areas. If so, costs will also increase and could help explain the recent decline in labour productivity. Estimates of the impact on costs range from $220 million to $1.5 billion annually.[30] New innovations do not yet appear to be emerging in the B.C. forest industry.[31]

In the United States, labour productivity rose until the mid-1980s, then slowed down; average annual MFP growth was negative after the mid-1980s. Unlike Canada, the U.S. has essentially exhausted its old growth forests. The decline in productivity thus could be due to this loss of a high quality natural capital and its substitution with secondary growth that produces less output per unit input. These events might be interpreted as a reduction in the sustainability of timber resources. However, the U.S., helped by favourable geography and climatic conditions, has been moving toward more intensive forest practices – plantation forests. Innovations in timber production are being used to increase productivity. These include use of biotechnology and genetic selection for high yield species, more intensive use of fertilizers and pesticides, and forest practices such as optimal thinning and irrigation. The data on labour productivity and MFP in the U.S. forest industry does not extend beyond the early 1990s, so it is too early to tell if the investment in new forest technology will improve productivity. There are also environmental implications of intensive forest management; monoculture and increased use of fertilizers and pesticides may adversely affect other industries, wildlife, and reduce biodiversity.

The examples from the four industries illustrate the diversity of responses to changing levels of natural capital and impacts of regulation. There is ample evidence of adoption of new technologies to mitigate or offset declining stocks of natural capital. What are the implications for sustainability? Two questions arise. First, is technological change and innovation necessary to ensure productivity growth in natural resource sectors? The answer appears to be yes for the examples shown. None of the cases above suggest significant threats to sustainability of production of these natural resources, or in turn, production of goods using them as inputs.[32] But it is clear that technological change has helped keep production levels from falling and/or costs from rising as much as they would have without innovation. The second question is how good is the past as a predictor of what to expect in the future with regard to technological changes and

[30] See van Kooten (1994), Haley (1996), and Binkley (1994). The current provincial government is in the process of changing provisions of the Forest Practices Code.

[31] These comments are more applicable to coastal logging than interior production and reflect a host of factors in addition to the supply natural capital, e.g., U.S./Canada exchange rates and the soft-wood lumber dispute with the United States.

[32] Recall that fisheries were identified in an earlier section as a renewable natural resource industry that appears to be unsustainable.

innovation? This brings us back to the issues of identifying how essential types of natural capital are to sustainable production and to see which sectors of the economy are at more risk with regard to their dependence on natural capital. This topic requires more research.

Unmeasured Factors in Productivity Growth: Environmental Services

The discussion to this point has focused on natural capital in the form of natural resources. Environmental resources are the other major type of natural capital. Unlike most of the examples above, environmental resources are essential to sustained life of humans and all species. The critical issue is determining thresholds. We can sustain consumption and production with a degraded natural environment, for example, lower air quality, a depleted stratospheric ozone layer, less biodiversity, fewer natural areas, climate change that raises average temperatures and increases variability of weather events such as intense storms, flooding, unseasonal temperatures, and so on. There will be tradeoffs in the form of higher insurance and health costs, loss of enjoyment from natural areas, less outdoor recreation, and higher expenditures to mitigate and adapt to the effects of ecosystem degradation. But, as ecosystem natural capital declines and/or the stock of accumulative pollutants builds up over time, there may come a time when productivity declines because of the loss of natural capital, and with it, comes a decreasing quality of life.

We do not yet have sufficient indicators of ecosystem degradation to be able to determine the impact of environmental natural capital on productivity. This is an area of active research and data collection by governments, NGOs, and research institutes worldwide. One problem is that there is no comprehensive measure of environmental capital. There are many indicators – ambient air quality, emissions of specific pollutants to air, water, and land, amount of protected lands, crude measures of biodiversity, and so on. But what is one to do with these numbers? How can they be linked to productivity and in turn, to the sustainability of consumption over time? Various organizations have compiled sustainability indexes from the indicators of environmental capital (and other variables). The problem is that these are largely 'black box' exercises that impose weights on each indicator to perform the aggregation. In principle, these weights should be the proportionate contribute of each indicator to the outcome variable (e.g., sustained production, quality of life). But without any sort of 'production function' that shows how the various environmental inputs are combined to produce output, the weights become arbitrary and often, subjective. This does not mean that these exercises are without value. They are a start, and if construction of the index is transparent and consistently measured over time, can help provide a picture of the role of environmental capital in sustaining economies.[33]

[33] See, for example, the sustainability index *2002 Environmental Sustainability Index,* produced by the World Economic Forum in collaboration with the Yale Center for Environmental Law and Policy, and Columbia University's Center for International Earth Science Information Network. Two of their recent reports are *2002 Environmental Sustainability Index* and *Pilot Environmental Performance Index*, available at: www.ciesin.org/indicators/ESI/ESI2002-11Feb02tot.pdf and www.ciesin.org/indicators/ESI/ESI2002-11Feb02.pdf.

A more modest approach has been to examine the contribution of environmental natural capital to productivity growth in the context of specific industries. The effect of leaving environmental capital out of estimates of productivity is analogous to that of leaving out natural resource capital; MFP will be overstated when environmental capital is growing and understated when it is declining. As environmental capital is used up, its price will rise if markets work to reflect the scarcity of environmental goods or by greater public awareness of benefits of environmental goods leading to pressure on governments for more regulation. If the price goes up and environmental capital is not included as an input, measured productivity growth will understate the extent of real productivity growth, with the divergence a function of the amount of environmental capital as a proportion of total inputs. If environmental capital is an insignificant input, then measured productivity will be a good estimate of actual productivity.

Several studies have tried to estimate the difference in MFP with and without environmental capital. Repetto et. al. (1996) calculated MFP with and without environmental capital for U.S. industries expected to have varying degrees of environmental capital use. They impute a value to emissions of an industry based on estimates of damages from pollution. If pollution levels fall, the net value of output rises more rapidly than when pollution levels are not incorporated. As Kolstad (2000) notes, this is not quite the same as changing the price of the environment over time, but is conceptually similar. Two industries – electricity generation and agriculture, illustrate the nature of their results for the period 1970 to 1990. As noted above, the U.S. government introduced air pollution regulations in the 1970s. This increased the cost of using the natural environment to electrical utilities, but had little effect on agriculture. The traditional measure of MFP shows a decline in productivity growth of about 9 percent over the period. But if environment is included as an input, productivity grows at around 12 percent over the period, relative to a 1970 base year. The divergence in MFP with and without environmental services is negligible for agriculture.

Conrad and Morrison (1989) also look at the role of environmental regulation on productivity growth. They assume that pollution regulations are socially efficient in that they correctly balance the marginal damages of pollution with the marginal costs of abatement. This is unlikely to be the case in practice. Secondly, they assume that pollution abatement is entirely a capital expenditure. This is also not true, but is not a bad proxy for many manufacturing industries (their data set). Looking at the United States, Canada, and Germany, they find for the period when environmental regulations were minimal (1960-67), traditional productivity growth measures were the approximately the same as an estimate of productivity inclusive of environmental inputs. But over the period 1972 to 1980, a period where many environmental regulations were introduced, the traditional measure understated the environment-adjusted measure (annual average rates of 2.2 versus 2.4 percent respectively). The effects were less pronounced for Canada (a divergence of 0.06) and Germany (divergence of .14). During the 1972 to 1980 period, Canadian environmental regulation was on average much less stringent that that of the United States. These results suggest that measured productivity growth is understated in periods where environmental regulations are tightening, to reflect growing scarcity of environmental quality.

Swinand (1999) calls MFP adjusted for changes in the level of pollution, 'total resource productivity' (TRP). Estimating production functions for different regions of the United States ,[34] he measures both MFP and TRP for agriculture, using pesticide pollution as his environmental variable. His results substantiate those of Repetto et al. regarding the small impact of environmental regulation on agriculture. He finds that when growth in pollution levels exceeded growth in output, TRP was less than MFP. For example, over the period 1989 to 1993, agricultural output was growing at an annual rate of 1.1 percent, pollution was falling by 29.5 percent, and TRP exceeded MFP by .15 percent per year (1.36 versus 1.21 percent). His results indicate the level of complexity needed to properly establish the relationship between MFP and TRP. Doing this at the level of the aggregate economy is a daunting task.

A very crude estimate of the relationship between GDP and pollution is illustrated for Canada in Figure 12. The ratio of GDP to ambient concentrations of the five air pollutants responsible for deterioration of urban and regional air quality is shown. While the slopes of the curves vary considerably, the ratio is rising except for ground-level ozone (O_3).[35] From 1979 to 1996, output growth does not appear to be coming at the expense of lower levels of aggregate air quality in the country.[36] These numbers are only suggestive of a trend. Air pollutants are one indicator of environmental quality. Other environmental indicators suggest a deterioration of environmental capital (e.g., declining water quality in some regions of the country, loss of ecosystems). Much more work is needed to address the links between productivity growth and environmental capital.

Insert Figure 12 near here

Do Productivity Estimates Help Predict Sustainable Economies?

This paper has examined productivity in Canadian natural resource industries in some detail to see if depletion of natural resource capital has affected productivity growth. To a much lesser extent, the relationship between environmental natural capital and productivity growth has also been addressed. Limitations of data and lack of studies prevent a more in-depth examination of natural capital. Do any conclusions follow from this discussion regarding sustainability? Is Canada on or off a sustainable path that ensures continued production and consumption over time, without destroying our natural

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[34] Also see Acharya (1998), Smith (1998), and Weaver (1998) for discussion of the theoretical issues involved in incorporating pollution into productivity estimates.
[35] Ground-level ozone is an input of urban smog and associated with adverse health effects. The GDP to ozone curve is relatively flat over the period, showing neither continual improvement, nor decline.
[36] The data also obscures regional and daily variations in air quality. Average ambient air quality does not reflect spikes in pollutants that may occur within a given day. Days of poor air quality are correlated with higher death rates from lung and heart disease, a higher incidence of asthma attacks, and other adverse events. While likely not affecting aggregate productivity, these variations in ambient quality are most definitely quality of life concerns to individuals.

environment? We don't know. The 'good news' and 'bad news' can be summarized as follows.

On the positive side, it appears that in many resource industries, changes in the stock of natural capital (depletion for most natural resources) have not lead to a decrease in labour productivity or MFP. Fishing and trapping is the only resource sector that has lower MFP in the most recent year (1998) than in the 1984 base year. Technological change, whether induced by environmental regulation or depletion of the natural capital stock, appears to be contributing to continued productivity growth. Production of these natural resources (except fisheries) has been sustainable despite falling levels of natural capital. For the economy as a whole, it was suggested that the natural resource inputs, with the exception of energy, may represent a smaller input share in aggregate production than they did in the past. This changing composition of output also implies continued sustainability because labour and human capital, reproduced capital, and other materials appear to be substitutes for natural capital. Canada is a small open economy and as our stocks of natural capital diminish, inputs from other countries can take their place. This, too, may contribute to sustained productivity growth domestically (but have adverse effects on the sustainability of other country's economies).

There is however a dark side, or at least a high degree of uncertainty about the contribution of natural capital to productivity growth and sustainability. The fishing industry and fish stocks in general (e.g., also for sport fisheries) are in trouble. These are predominately open access resources where regulations have not worked to ensure sustainable stocks. Productivity (labour and MFP) has been falling over time. These resources are certainly not essential to continued production and consumption. People can substitute other food for fish. There is also the growth of fish farming, a very controversial issue in terms of its environmental impacts. What we don't know is what the impact will be on aquatic ecosystems of the loss of a number of fish species and whether in turn, that will have other negative spillovers for society. Energy resources are another case where it is not yet clear whether our path is sustainable. Productivity growth has helped sustain production of fossil fuels in recent years, but natural capital stocks are declining. There are substitutes for fossil fuels and if markets are functioning properly, rising prices for increasingly scarce fuels should accelerate development of technologies to substitute alternative energy sources such as fuel cells. Fossil fuels are also major sources of pollution, so their use as natural resource inputs also has implications for stocks of environmental capital. This is where our ignorance about the state of our environmental capital and its impact on productivity and sustainability is evident. We don't know if we are passing thresholds (e.g., with climate change) that will lead to very high costs of mitigation or adaptation in the future, reduce productivity, and hence, have driven us on to a non-sustainable path. This uncertainty is why a number of researchers advocate taking a precautionary path that requires the use of efficient environmental regulation as a necessary complement to economic growth.

Estimating productivity changes for the Canadian economy, ideally adjusted to reflect changes in natural capital, is a worthwhile undertaking. Doing it properly requires more data and analysis at both aggregate and micro levels. When productivity begins falling in sectors that rely on natural capital, it suggests that technological change is no longer keeping up with depletion, that substitute inputs are not readily available, and regulation is not addressing the market failures associated with using resources (open access, pollution externalities). Reductions in productivity can serve as a warning that production and consumption may be moving on a non-sustainable path; decision makers and society should take notice.

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Figure 1: Timber Harvests and Assets, 1961-1997:   Statistics Canada, Canada Timber Assets (Volume), Opening Stock. Table Number: I530030, Timber Harvests. Table Number I530030.

Figure 2: Canadian Energy Reserves and Production, 1970-1998: Natural Resources Canada, *Energy in Canada 2000.*   www. nrcan.gc.ca/es/ener2000.

Figure 3: Constant Dollar Prices of Crude Oil and Natural Gas Exports, 1981-1998. Natural Resources Canada, *Energy in Canada 2000.*   www. nrcan.gc.ca/es/ener2000.

Figure 4: Implicit Price of Timber, 1961-1998. Computed from Statistics Canada, Timber Harvests and Indexes of Real GDP in Logging and Forestry, Table Number: I607603.

Figure 5: Energy to GDP Ratios. Natural Resources Canada, *Energy in Canada 2000.*   www. nrcan.gc.ca/es/ener2000, Statistics Canada, Gross Domestic Product at Factor Costs..

Figure 6: Labour Productivity in Renewable Resource Industries, 1961-2000. Statistics Canada, Indexes of Real GDP per Hour Worked, Table Numbers: I610101, I610102, I610103.

Figure 7: Labour Productivity in Nonrenewable Resource Industries, 1961-2000. Statistics Canada, Indexes of Real GDP per Hour Worked, Table Numbers: I610204, I610310, I610205.

Figure 8: Multi-factor Productivity: Renewable Resources vs. All Industries, 1984-1998. Centre for the Study of Living Standards, based on Statistics Canada, *Labour Force Survey*, GDP, and Capital Stock Data, as cited in Natural Resources Canada, *Energy in Canada 2000.*   www. nrcan.gc.ca/es/ener2000.

Figure 9: Multi-factor Productivity: Nonrenewable Resources vs. All Industries, 1984-1998. Centre for the Study of Living Standards, based on Statistics Canada, *Labour Force Survey*, GDP, and Capital Stock Data, as cited in Natural Resources Canada, *Energy in Canada 2000.*   www. nrcan.gc.ca/es/ener2000.

Figure 10: MFP vs. Labour Productivity Growth: Forestry and Logging, 1984-1997. Data from Figures 5 and 7.

Figure 11: Natural Capital to Labour Ratio: Logging & Forestry, 1984-1997. Computed from Statistics Canada, Canada; Timber Assets (Volume), Opening Stock. Table Number: I530030 and Statistics Canada, All Employees/Logging and Forestry, Table Number: L656870.

Figure 12: GDP to Pollution Ratios, Criteria Air Pollution Ratios, 1979-1996. Statistics Canada, Gross Domestic Product at Factor Costs. Environment Canada, Environment Canada (1999) *State of the Environment, SOE Technical Supplement No. 99-1*, p. 5. *Urban Air Quality, Technical Appendix*, Spring 1999, www.ec.gc.ca/ind/English/Urb_Air/Tech_Sup/uasup5_e.cfm.

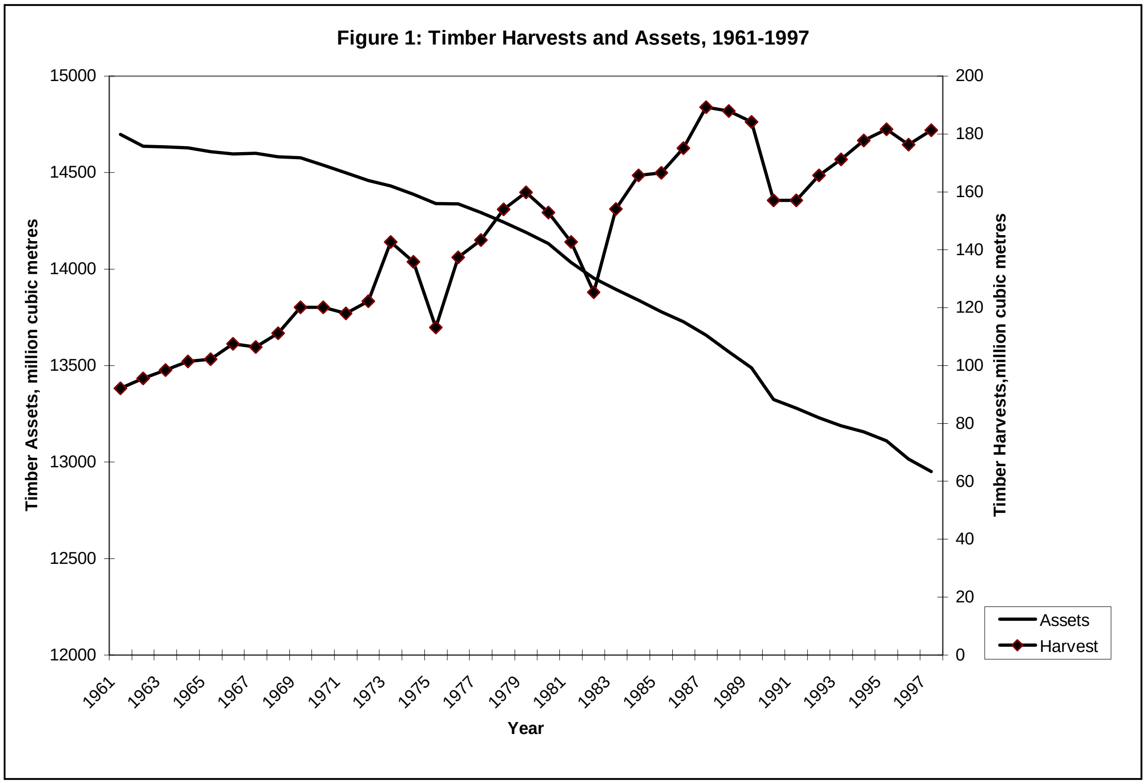
Figure 1: Timber Harvests and Assets, 1961-1997
Timber Assets, million cubic metres
Timber Harvests,million cubic metres
15000
14500
14000
13500
13000
12500
12000
200
180
160
140
120
100
80
60
40
20
0
1961
1963
1965
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1991
1993
1995
1997
Year
Assets
Harvest

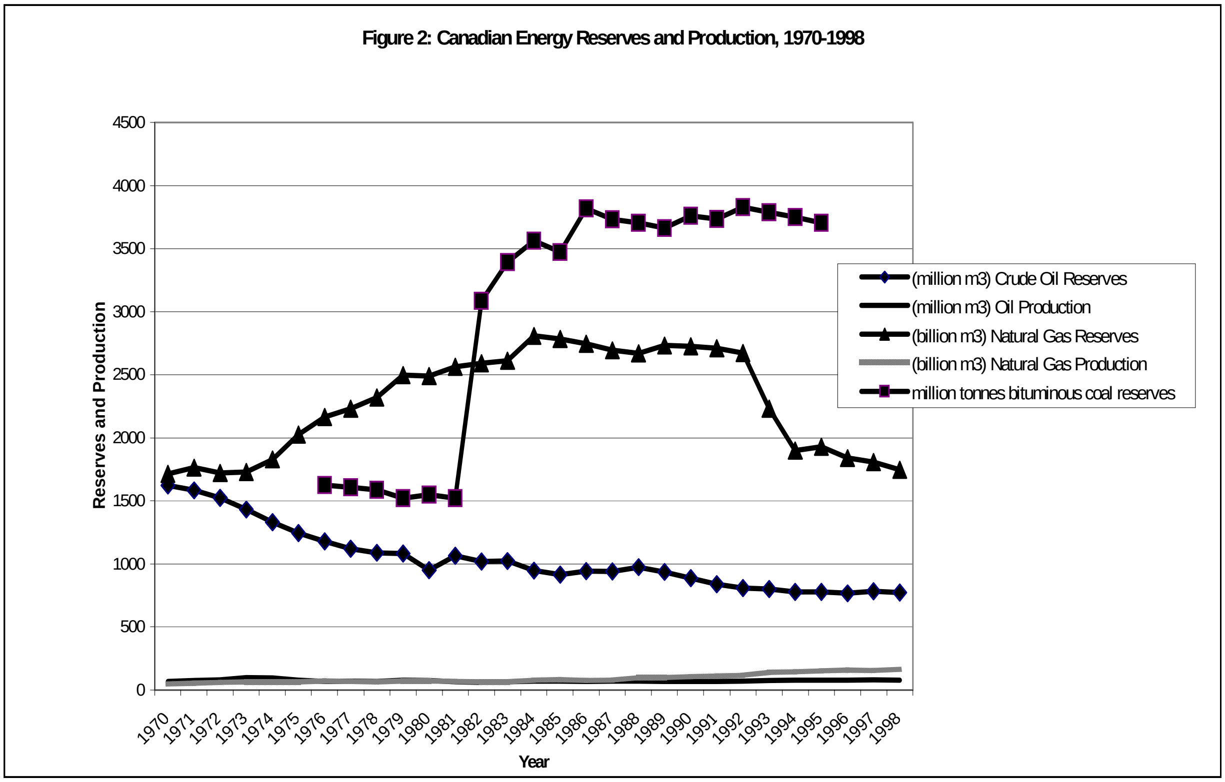


Figure 2: Canadian Energy Reserves and Production, 1970-1998
Reserves and Production
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998
Year
(million m3) Crude Oil Reserves
(million m3) Oil Production
(billion m3) Natural Gas Reserves
(billion m3) Natural Gas Production
million tonnes bituminous coal reserves

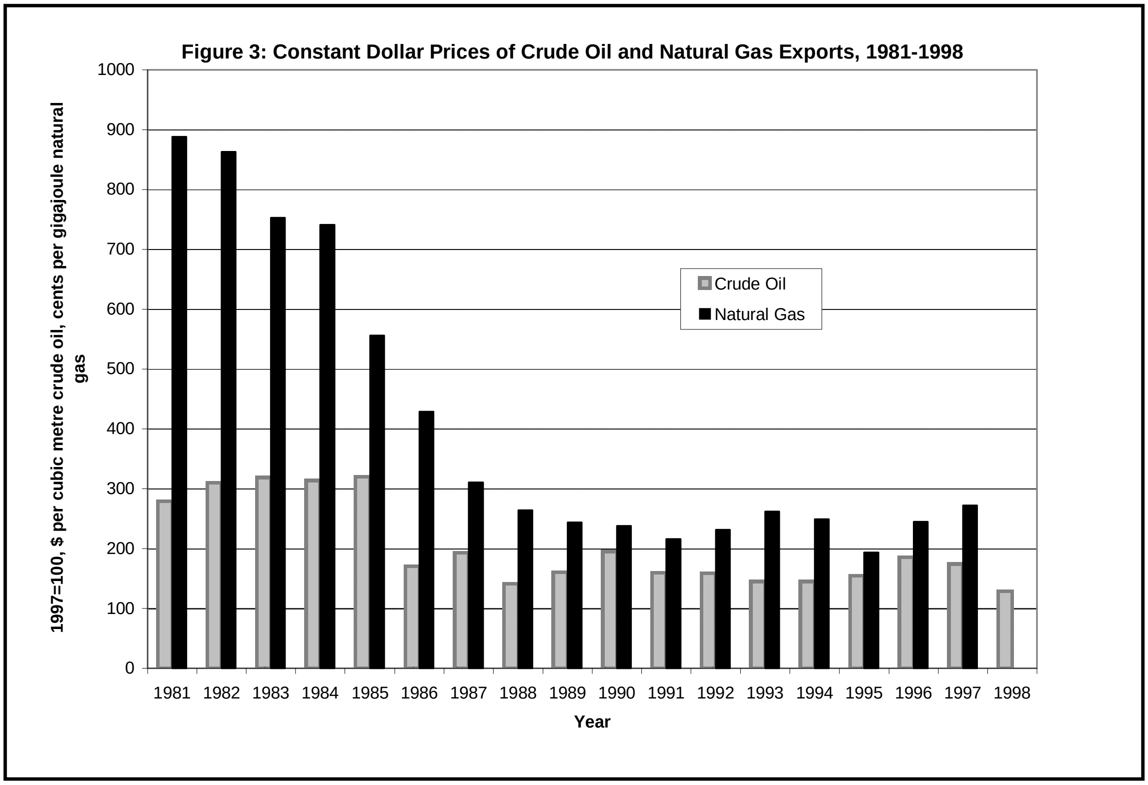


Figure 3: Constant Dollar Prices of Crude Oil and Natural Gas Exports, 1981-1998
1997=100, $ per cubic metre crude oil, cents per gigajoule natural gas
1000
900
800
700
600
500
400
300
200
100
0
Crude Oil
Natural Gas
1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998
Year

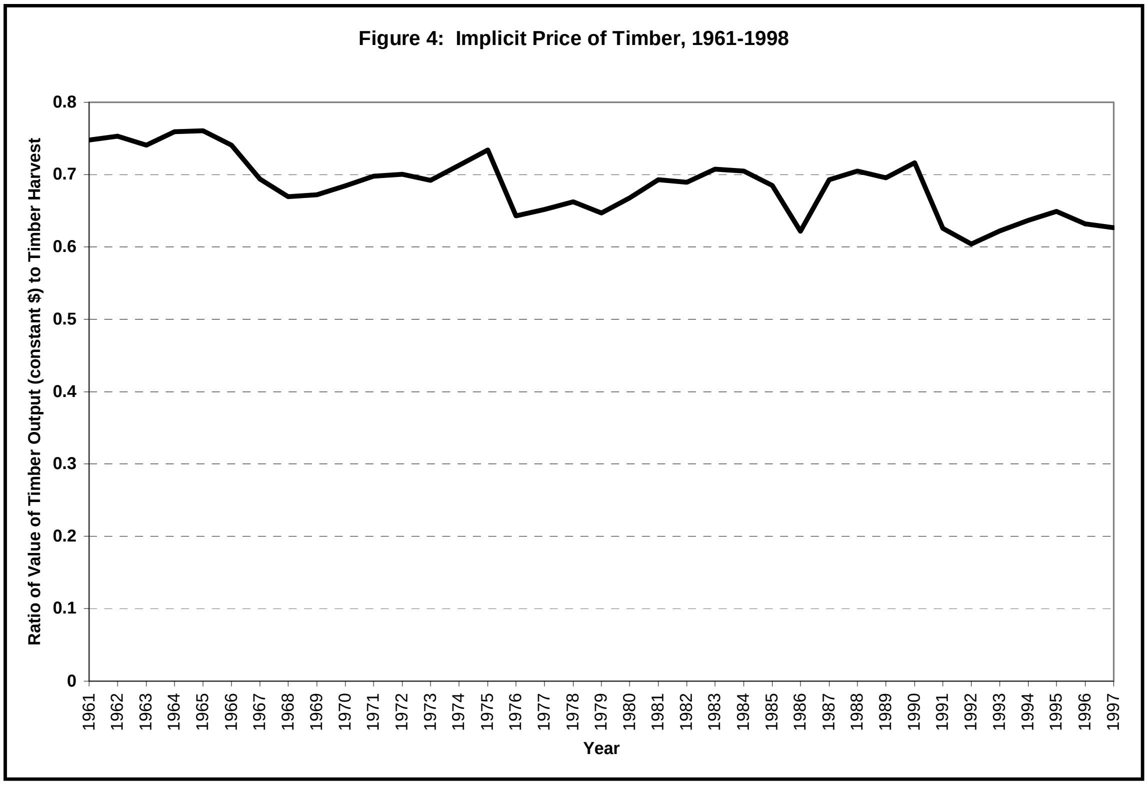


Figure 4: Implicit Price of Timber, 1961-1998
Ratio of Value of Timber Output (constant $) to Timber Harvest
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
Year

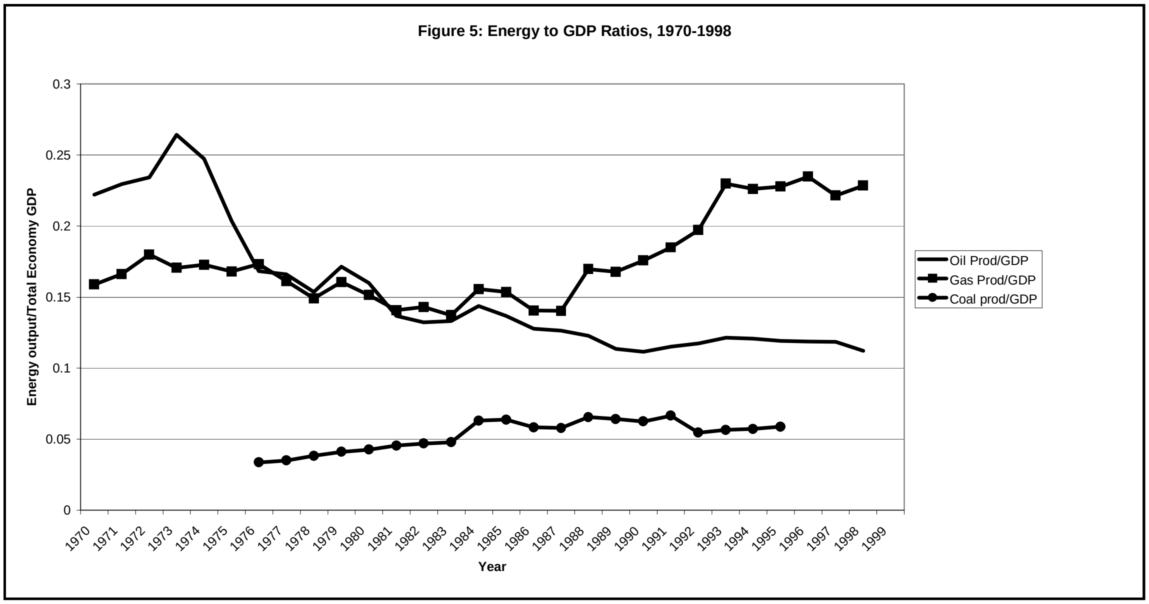


Figure 5: Energy to GDP Ratios, 1970-1998
Energy output/Total Economy GDP
0.3
0.25
0.2
0.15
0.1
0.05
0
1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
Year
Oil Prod/GDP
Gas Prod/GDP
Coal prod/GDP

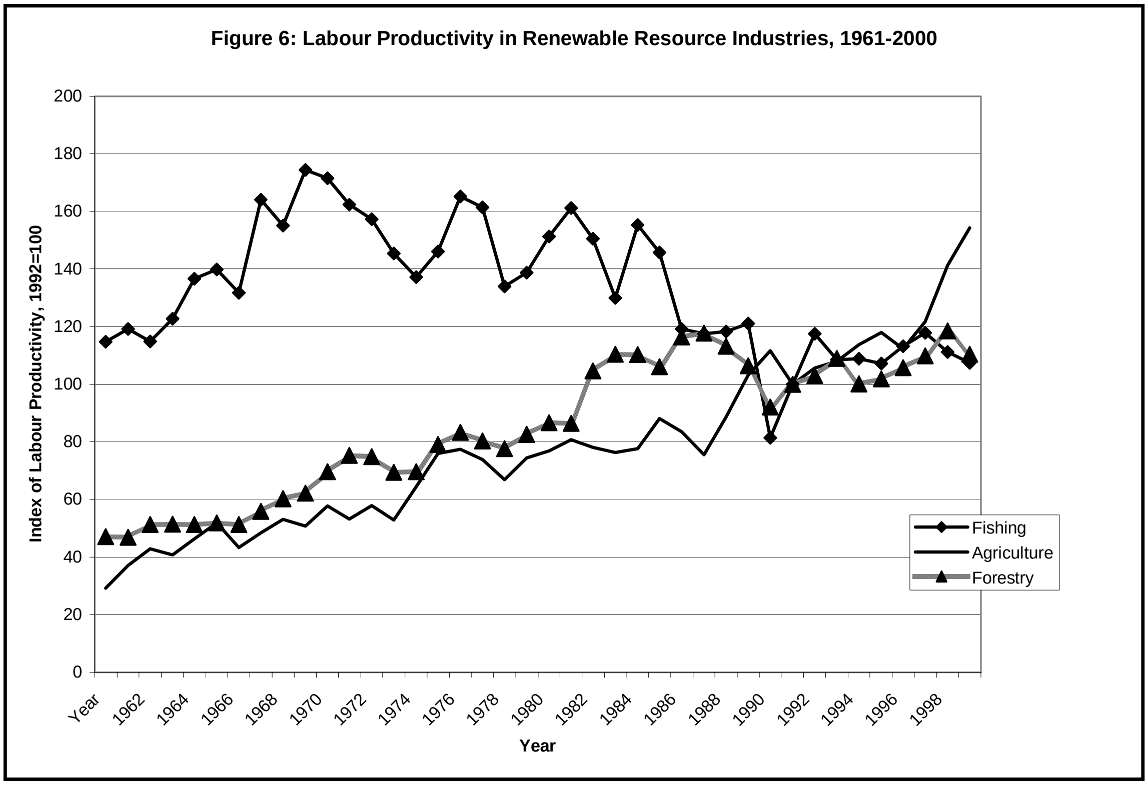


Figure 6: Labour Productivity in Renewable Resource Industries, 1961-2000
Index of Labour Productivity, 1992=100
200
180
160
140
120
100
80
60
40
20
0
Year
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Year
Fishing
Agriculture
Forestry

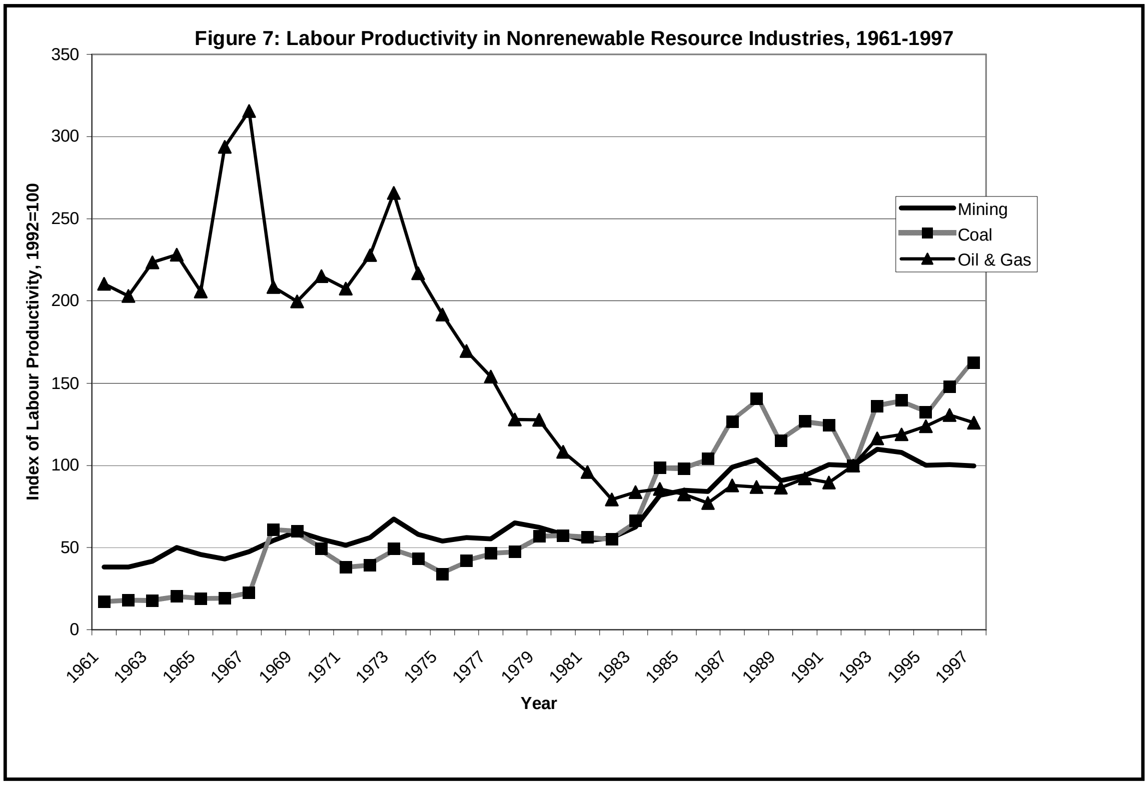


Figure 7: Labour Productivity in Nonrenewable Resource Industries, 1961-1997
Index of Labour Productivity, 1992=100
350
300
250
200
150
100
50
0
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
Year
Mining
Coal
Oil & Gas

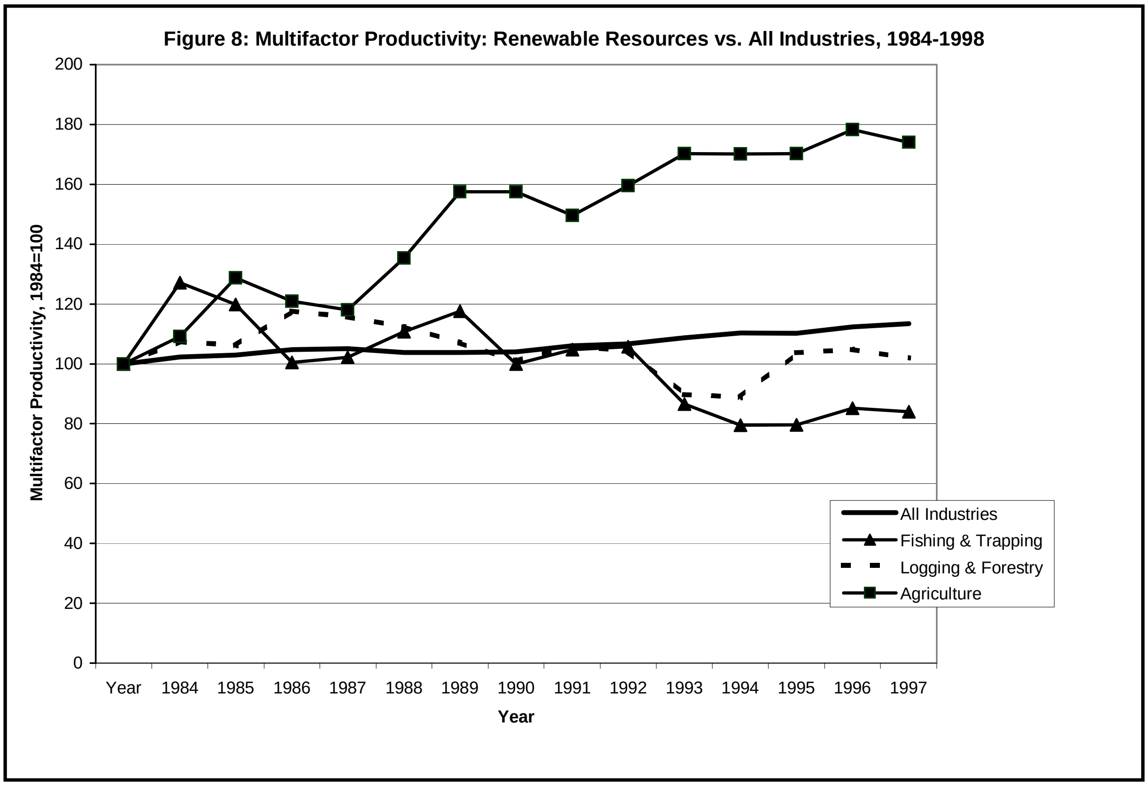


Figure 8: Multifactor Productivity: Renewable Resources vs. All Industries, 1984-1998
Multifactor Productivity, 1984=100
0
20
40
60
80
100
120
140
160
180
200
Year
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
Year
All Industries
Fishing & Trapping
Logging & Forestry
Agriculture

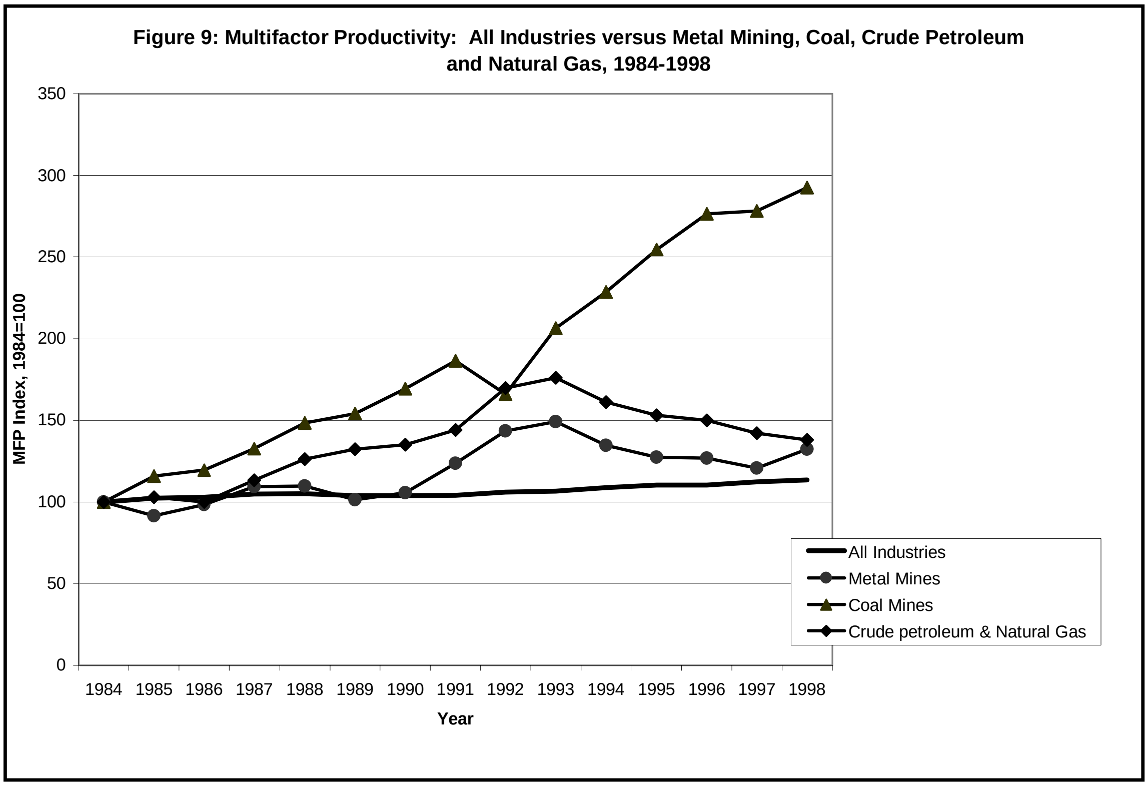
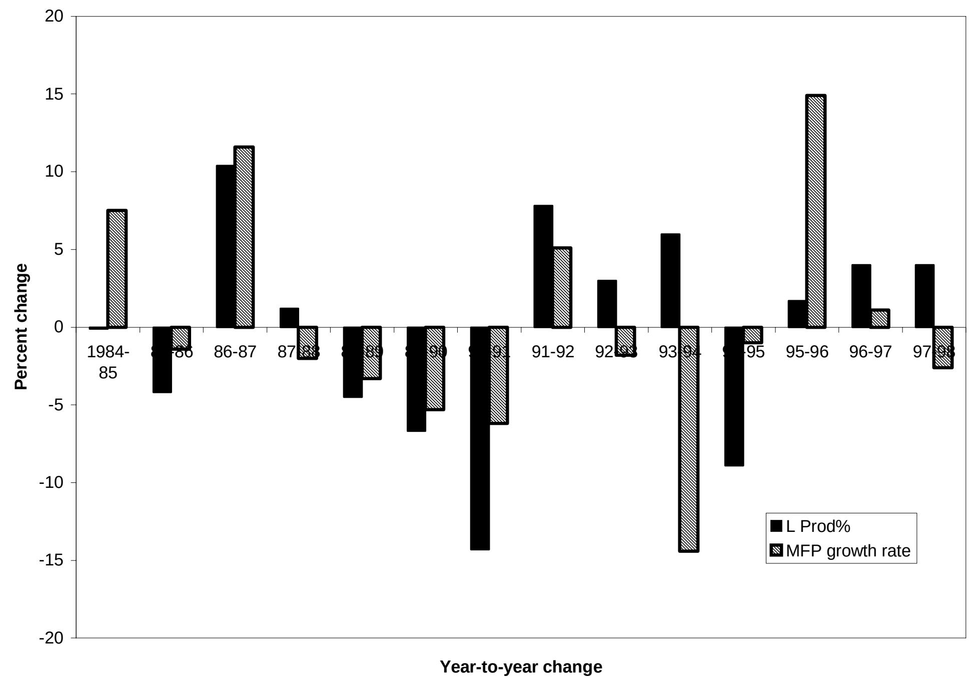


Figure 9: Multifactor Productivity: All Industries versus Metal Mining, Coal, Crude Petroleum and Natural Gas, 1984-1998
MFP Index, 1984=100
350
300
250
200
150
100
50
0
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Year
All Industries
Metal Mines
Coal Mines
Crude petroleum & Natural Gas

Figure 10: MFP vs. Labour Productivity Growth: Forestry & Logging, 1984-1998



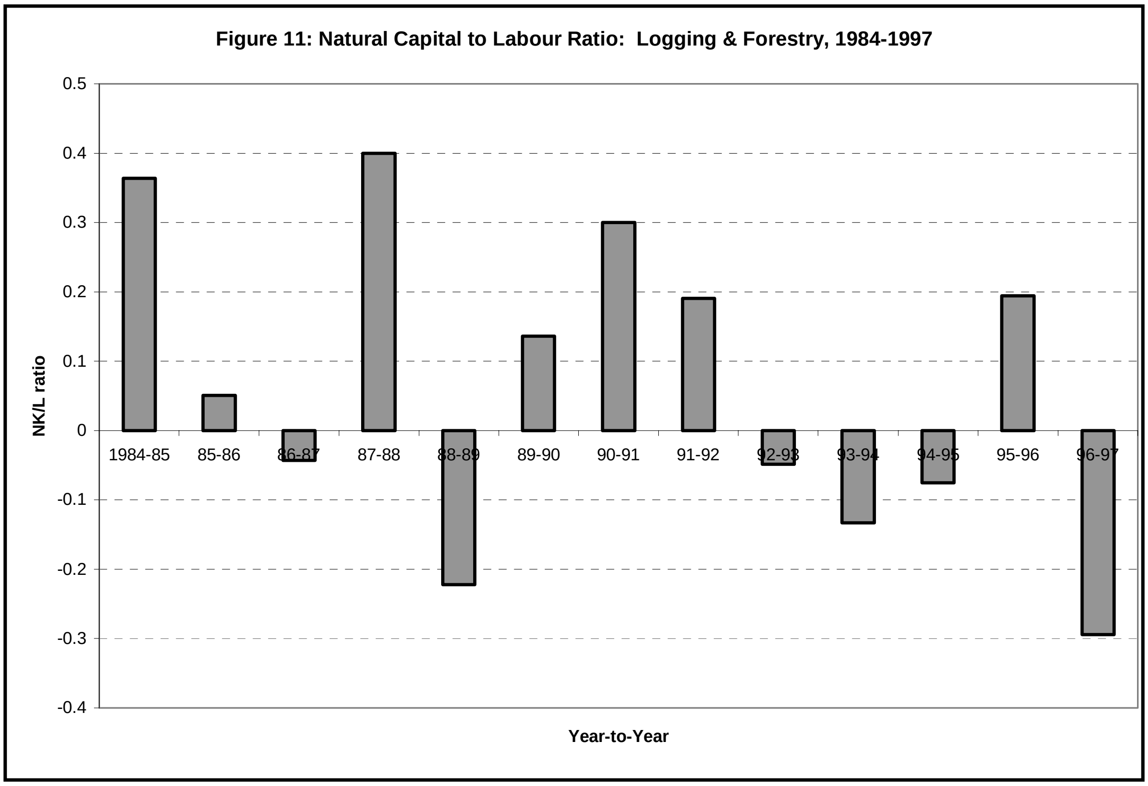


Figure 11: Natural Capital to Labour Ratio: Logging & Forestry, 1984-1997
NK/L ratio
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
1984-85
85-86
86-87
87-88
88-89
89-90
90-91
91-92
92-93
93-94
94-95
95-96
96-97
Year-to-Year

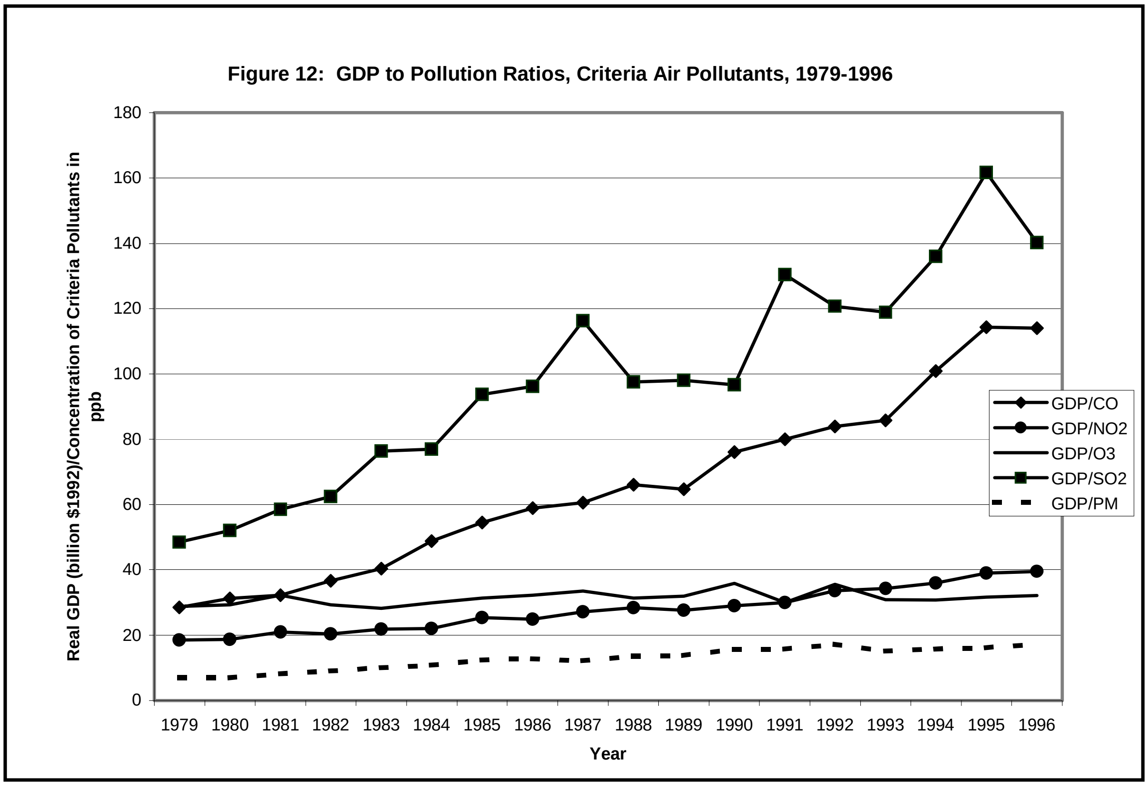


Figure 12: GDP to Pollution Ratios, Criteria Air Pollutants, 1979-1996
Real GDP (billion $1992)/Concentration of Criteria Pollutants in ppb
Year
180
160
140
120
100
80
60
40
20
0
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
GDP/CO
GDP/NO2
GDP/O3
GDP/SO2
GDP/PM