Linking Natural Capital & Productivity

The Rationale for Building an Environmentally Adjusted Measure of Productivity

About the Project

This paper serves as the foundation for a project titled "Linking Natural Capital and Productivity: A Strategy to Improve Canada's Economic and Environmental Performance." 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 productivity specifically.

While it is now commonly accepted that economic activity and the state of our environment are linked, many economic measures still fail to incorporate the environment – both the things we draw from it and the pollution we release into it. By developing and calculating measures of productivity that include natural capital, Canada may be able to better understand these linkages. This, in turn, may lead to the identification of strategies that can help Canada become more efficient and innovative in the use and protection of natural capital, and thus more productive and more prosperous.

Using the forestry sector as a case study, this project aims to construct an environmentally adjusted measure of multifactor productivity. In doing so, we aim to add another layer of understanding to the environmental and economic performance of this sector. The proposed measure will have relevance to the Canadian economy as a whole.

Partners & Acknowledgments

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.

An unpublished paper, ***"The Double Dividend: Defining a Framework for Understanding our Natural Capital"*** by Justin To and Laurel Pentalow, served as the intellectual foundation for developing this project.

Primary research and writing were conducted by Michelle Brownlee with assistance from Courtney Kehoe and Mishaal Sinha. Research initiation and direction provided by Stewart Elgie. Thank you to members of the project team who provided valuable guidance and comments, in particular Rob Smith, Geoff McCarney, Andrew Sharpe and Céo Gaudet. Thank you to Autobox Media for graphic design and report layout.

A complete list of project references, sources and key terms can be found at **www.sustainableprosperity.ca/nkp**

Key Messages

- Like all forms of wealth, we must understand, measure and manage our natural capital in order to use it optimally. With Canada's economy and Canadians' wellbeing closely linked to natural capital, there is an imperative – both environmental and economic – to sustain our natural capital.

- Mismanagement of our natural capital asset can lead us to depreciate its value too quickly, jeopardizing the potential flow of goods and services it can provide in the future; however, just as there is a downside to misusing our natural asset, so is there a potentially large upside to managing it well. Currently, on a global scale, available resource efficiency and productivity improvement opportunities have been estimated to be valued at $2.9 trillion by the year 2030 [1]. The countries, sectors and companies who grasp these opportunities will be rewarded with cost savings, growing markets, enhanced reputations and export potential.

- Productivity is a key measure of how efficient, innovative, and competitive a country, company or sector is. However, current productivity metrics largely fail to reflect natural capital; efforts to act as stewards of natural capital – thoughtfully managing its use over time – will largely not be reflected. In response to this shortcoming of conventional productivity metrics, environmentally adjusted measures of productivity can be constructed. These metrics incorporate environmental inputs and/or the output of pollution, and can add a new dimension to our understanding of productivity measurement and of our environmental performance.

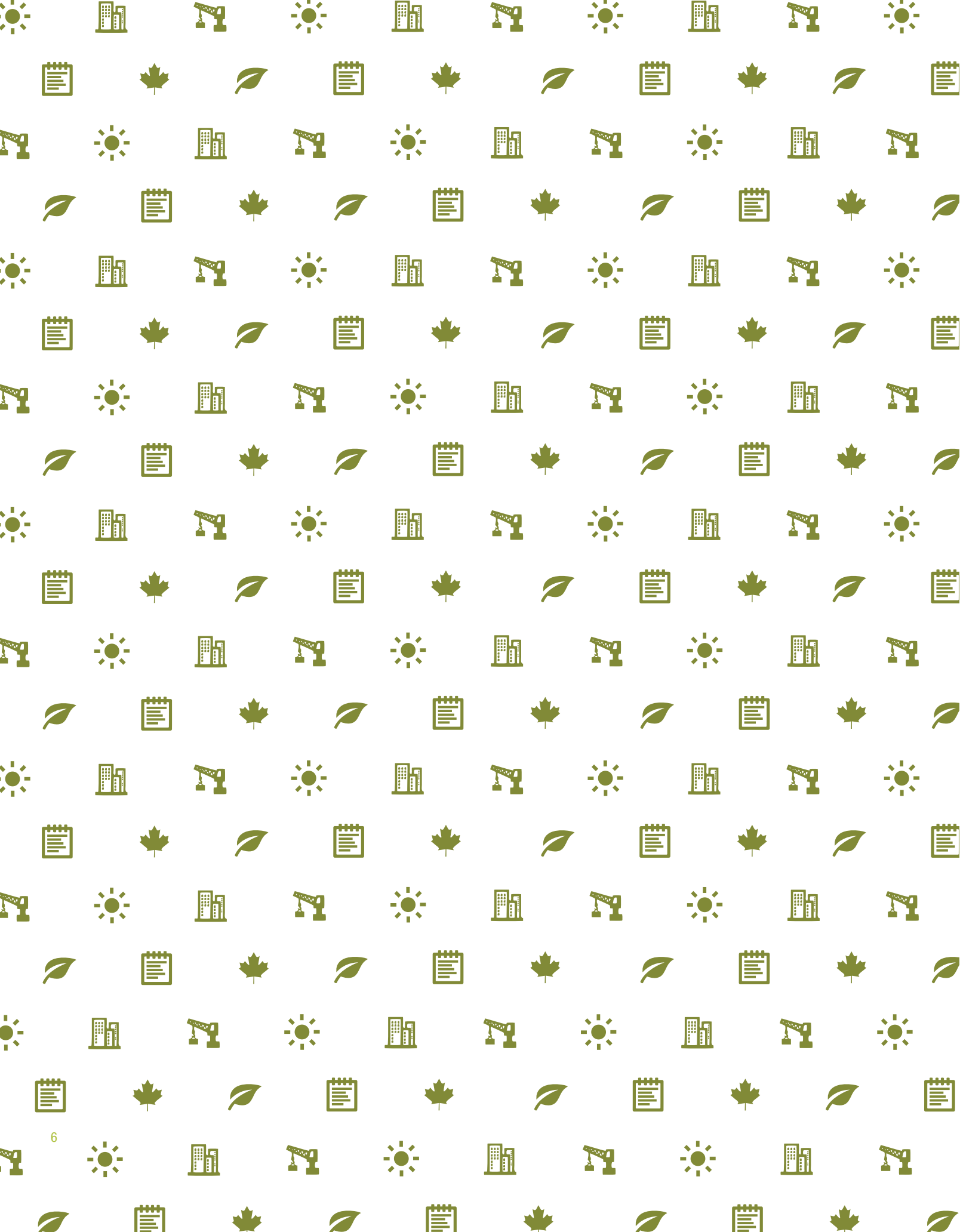
- Recent studies show that failing to include natural capital in multifactor productivity measurement leads to an underestimation of productivity growth, particularly in times of improving environmental performance.[2] Conversely, conventional measures of productivity may overestimate productivity growth if pollution is increasing, as compared to environmentally adjusted measures.

- Ultimately, using environmentally adjusted measures of productivity to inform decision-making would lead to better public policy, and those who successfully decouple economic activity from environmental impact will be recognized and rewarded.

- Exploring the links between natural capital and productivity measurement can provide insight on how our economic activity relies on the flows of goods and services provided by natural capital stocks, and on how pollution and other impacts of economic activity may depreciate the value of these stocks. There are challenging questions related to this field, such as: How do we measure and assess natural capital's role in our economic productivity? How is our natural capital's potential to provide value influenced by our current economic activity? What might we do better, in order to improve both our economic and environmental performance? While we aim to produce an environmentally adjusted measure of productivity, we are also seeking to raise the profile of these important questions, in hopes of encouraging further discussion and research.

1 R Dobbs et al. "Resource Revolution: Meeting the world's energy, materials, food and water needs." 2011, McKinsey Global Institute. http://www.mckinsey.com/insights/energy_resources_materials/resource_revolution

2 See Section 3 for references and specific findings.



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Canada's Natural Capital Wealth

"What right have you to take the word wealth, which originally meant "well-being," and degrade and narrow it by confining it to certain sorts of material objects measured by money."
— John Ruskin, English art critic (1810-1900)

That wealth encompasses much more than financial balances is widely recognized. While we identify monetary assets as a form of wealth, we increasingly understand that our health and ability to work, our machinery and buildings, and the assets found in our natural environment are also sources of wealth. We use these assets daily to produce the goods and services we value in order to increase our wellbeing.

However, the metrics used to understand our wealth are largely restricted to assets that have an observed value, namely those traded in the marketplace. Recent efforts have been made to build metrics that describe more fully the components of wealth. One such effort, the **Inclusive Wealth Index**[3], seeks to build a set of accounts that includes the social value of all of an economy's capital assets: (i) manufactured capital (e.g., roads, buildings, machines, and equipment), (ii) human capital (e.g., skills, education, health), and (iii) natural capital (e.g., sub-soil resources, ecosystems, the atmosphere).The third category, natural capital, is of particular interest to Canadians.

Natural capital comprises the elements of the environment that produce valued goods and services. Like all forms of wealth, we must understand, measure and manage our natural capital in order to use it optimally. While capital refers to the level or amount of a stock of an asset at a specific point in time, the flow of value it provides is measured over a period of time. The distinction between the stock of natural capital and the flow of value it provides is analogous to a bank account that holds a stock of money (i.e., financial capital) and provides a flow of value in the form of interest. The stock represents wealth, while the flow represents income. Just as a person or company can draw down a bank account such that it yields less income in the future, so too can we "draw down" our stock of natural capital.

> ***"Much as an investor will use financial capital to generate profits, a stock of forest or fish will provide a future flow of timber or food, which if used sustainably will provide long-term benefits to people."***[4]
>
> ***– The United Nations Environment Program (UNEP)***

This paper helps build the case for inclusion of natural capital in our understanding of wealth and thus for seeing natural capital reflected in our key economic metrics. The key objective of the project, as described in the "About this Project" Section on page 2, is to construct an environmentally adjusted measure of productivity generally, applied to the case study of forestry specifically. This section of the paper serves as an introduction; section 2 explains how natural capital is not fully reflected in economic metrics and describes the upside of better understanding natural capital's links with productivity, Section 3 focuses on environmentally adjusted metrics of productivity, and Section 4 looks forward to potential policy implications resulting from this project.

DEFINITION | ***Natural capital***

includes, first of all, the resources that we can easily recognize and measure such as minerals and energy, forest timber, agricultural land, fisheries and water. It also includes ecosystems producing services that are often 'invisible' to people such as air and water filtration, flood protection, carbon storage, pollination for crops, and habitat for fisheries and wildlife.

– Definition from the Wealth Accounting and the Valuation of Ecosystem Services partnership (WAVES) [5]

[3] UNU-IHDP and UNEP (2014). Inclusive Wealth Report 2014. Measuring progress toward sustainability. Cambridge: Cambridge University Press. For more information, refer to: www.inclusivewealthindex.org

[4] United Nations Environment Programme 2012 Natural Capital Declaration (Signed at Rio +20 Event) http://www.naturalcapitaldeclaration.org/the-declaration/

Canadians enjoy immense wealth as a result of Canada's natural environment. As a country, Canada controls one of the largest primary resource bases in the world; ranked third in the world for each of forested area, renewable freshwater resources and oil reserves, and ranked seventh for amount of arable land.[6]

Canada's mining, metals, forestry and energy industries alone "directly and indirectly accounted for almost one fifth of nominal GDP in 2013."[7] There are 800,000 resource sector jobs in Canada – the number grows to 1.8 million when jobs that supply the natural resources sector in industries such as construction, manufacturing, financial services and engineering are included.[8] The benefits also extend globally through international trade; in 2009, agricultural, energy, forestry and mining exports accounted for about 51% of Canada's total exports.[9]

Canada's natural capital is more than natural resources to be harvested. We benefit from the ecosystem services the environment provides such as the filtering of air by trees and the absorption of floodwaters by plains and wetlands. There is also the clean water provided to communities, the climate to grow crops, and the natural beauty and biodiversity that provide spiritual value to many Canadians.

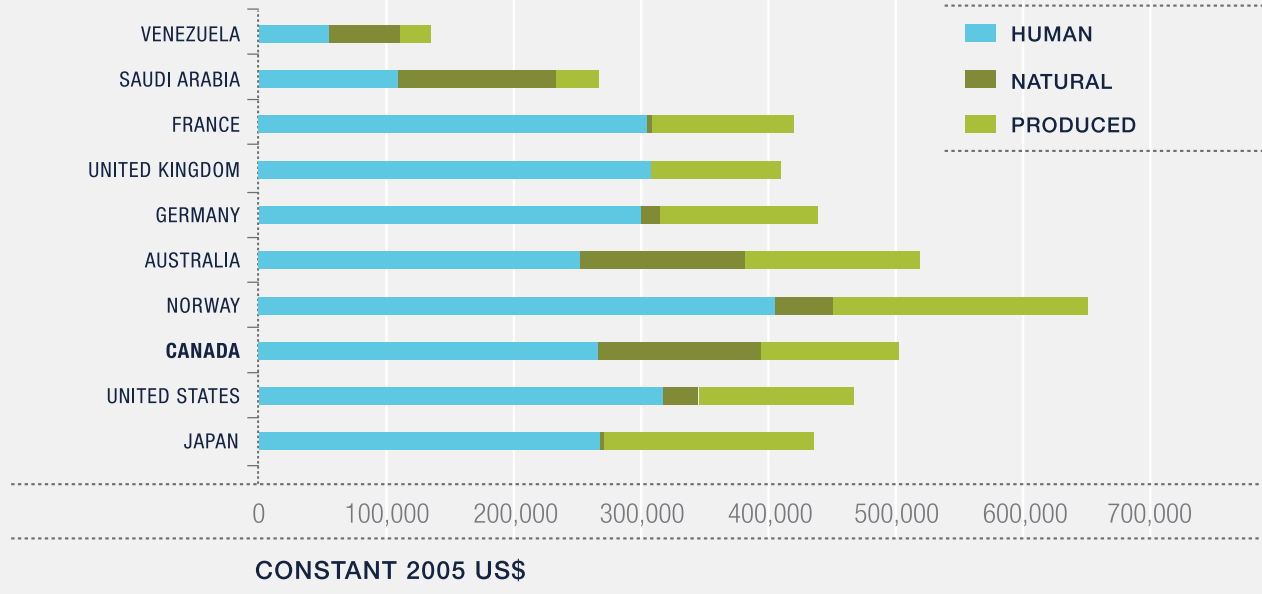
NATURAL CAPITAL IN OUR CITIES

A recent study by TD Economics considered the value of the natural capital of the urban forests in and around the greater Halifax, Montreal, and Vancouver areas and found that together the "stock" of more than 100 million trees they contain are worth an estimated $51 billion. When four key ecosystem services are considered – wet-weather control, air quality, energy savings and carbon sequestration – these three urban forests were found to provide a "flow" of environmental benefits of over $250 million per year.[10]

5 Wealth Accounting and the Valuation of Ecosystem Services https://www.wavespartnership.org/en/frequently-asked-questions-natural-capital-accounting-nca?active=3
6 Sustainable Prosperity, 2014 "The Importance of Natural Capital to Canada's Economy" available at http://www.sustainableprosperity.ca/article3869
7 Natural Resources Canada's "Key Facts and Figures on the Natural Resources Sector", available at: http://www.nrcan.gc.ca/publications/key-facts/16013#a1
8 ibid
9 Statistics Canada, Exports of goods on a balance-of-payments basis, retrieved from http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/gblec04-eng.htm on May 11, 2015
10 TD Economics Special Report, 2014, "The Value of Urban Forests in Cities Across Canada" Available at http://www.td.com/document/PDF/economics/special/UrbanForestsInCanadianCities.pdf. A separate study looked at the value of Toronto's urban forest: http://www.td.com/document/PDF/economics/special/UrbanForests.pdf

FIGURE 1

INCLUSIVE WEALTH PER CAPITA (2010)

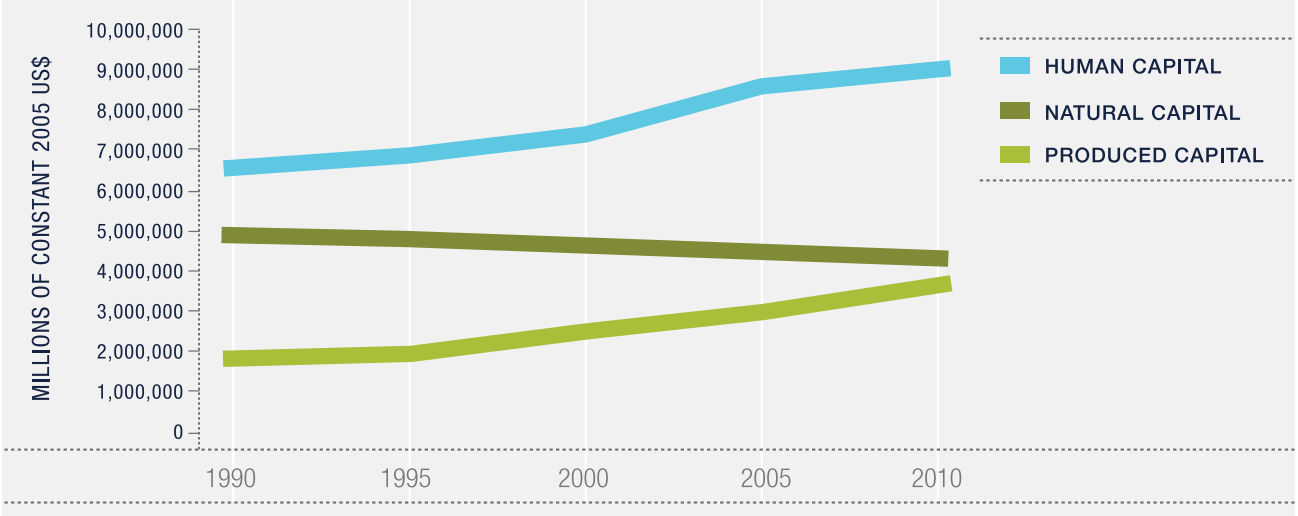


The Inclusive Wealth Index [11] is a comprehensive measure of wealth with metrics for human capital, produced capital and natural capital (where natural capital comprises fossil fuels, minerals, forest resources, agricultural land, and fisheries, including known reserves/stocks and production.)

FIGURE 1 shows that, on a per capita basis, **Canada** has among the hightest levels of total wealth and one of the greatest shares of wealth from natural capital, from among a group of comparable countries. FIGURE 2 shows that Canada's total levels of human and produced capital have been steadily increasing, while natural capital has seen a slow but steady decline.

FIGURE 2

TRENDS IN CAPITAL LEVELS IN CANADA



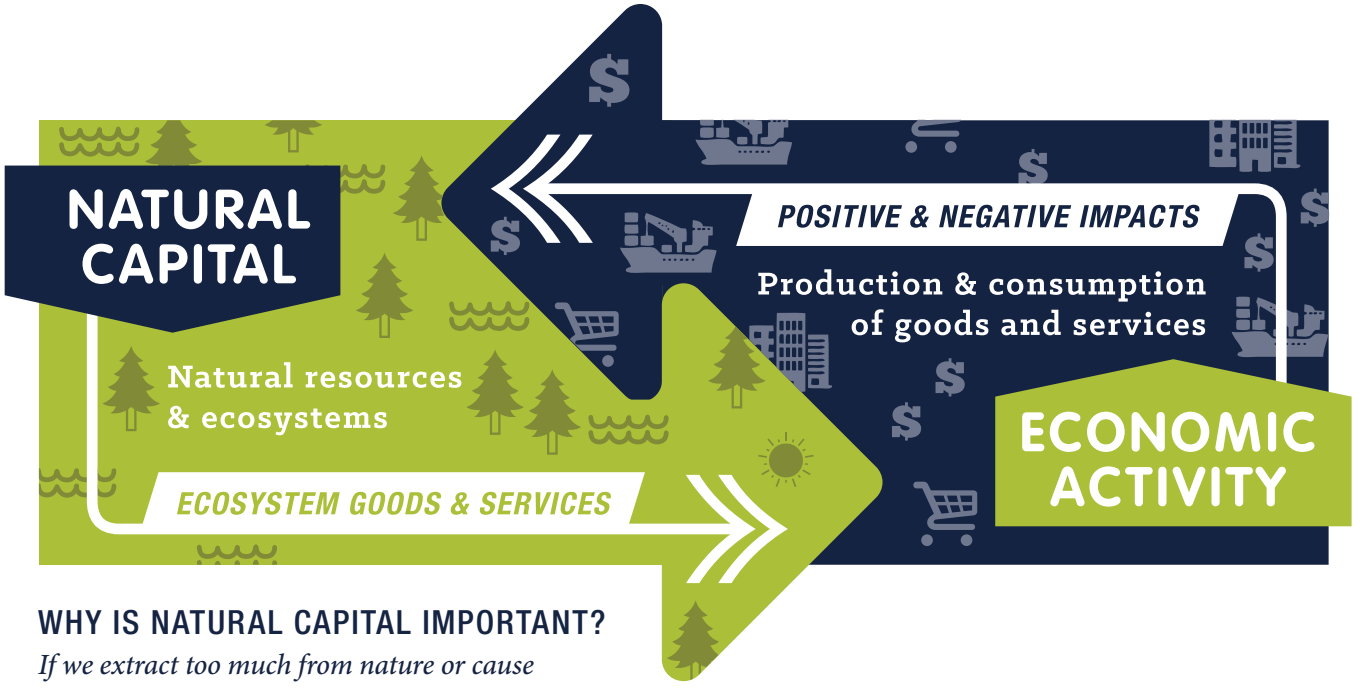
[11] University of the United Nations-International Human Dimensions Programme and United Nations Environment Programme, (2014). Inclusive Wealth Report 2014. Measuring progress toward sustainability. Cambridge: Cambridge University Press. For more information, refer to: www.inclusivewealthindex.org

Taking advantage of our natural wealth has allowed Canadians to prosper and achieve a high standard of living. However, while our use of natural capital to support economic activity has increased our wellbeing, at the same time biodiversity is in decline,[12] natural landscapes are being converted to other uses (including resource extraction sites, roads, cities, and agricultural lands), bodies of water are filling with plastic and other waste, and the climate is changing.

There are two main conceptual views of what limits human activity might be able to impose on natural capital use. The first, 'weak sustainability,' allows substitution of one form of capital for another, while an alternate view, 'strong sustainability,' recognizes that not all the functions of natural capital can be replicated by humans using other forms of capital. With some forms of natural capital, such as non-renewable resources, using natural capital implies drawing down our natural capital in order to create other forms of capital, like financial and human capital. However, natural capital in the form of ecosystems is more complex. Ecosystems have limits beyond which they cannot recover from human use – many of which we do not fully understand – and once gone, are largely irreplaceable. For instance, if a wetland that provides habitat for various species is drained, it may be possible to later restore the wetland, but the recreated wetland might not house the same species, filter water the same way, or provide the same floodwater mitigation benefits.

WHY IS NATURAL CAPITAL IMPORTANT?

Natural capital and economic activity are highly linked...



WHY IS NATURAL CAPITAL IMPORTANT?

If we extract too much from nature or cause environmental damage, we degrade our natural capital and put our economy at risk.

[12] http://assets.worldwildlife.org/publications/723/files/original/WWF-LPR2014-low_res.pdf?1413912230&_ga=1.63701482.432967438.142897105

When extraction and degradation of natural capital are not considered in decision-making, there is a risk of drawing down natural capital too quickly or losing significant or irreplaceable natural capital.[13] With so much of our economy dependent on natural capital, there is clearly a lot at stake for Canadians. We have an imperative – both environmental and economic – to sustain our natural capital. Understanding the importance of natural capital use and the adverse effects of its degradation can facilitate decision-making that incorporates both economic and environmental considerations. This is important to maintaining – and potentially increasing – Canadians' high standard of living.

Just as there is a downside to misusing our natural capital, so is there a potentially large upside to managing it well. McKinsey and Associates has estimated the total value to society associated with available resource efficiency and productivity improvement opportunities to be $2.9 trillion by the year 2030. With some environmental value added (such as a moderate carbon price of $30/tonne), the estimated value rises to $3.7 trillion.[14] The countries, sectors and companies who grasp these opportunities will be rewarded with cost savings, new technologies, growing markets, enhanced reputations and export potential. There is opportunity for Canada, as a country with large natural capital wealth and many sectors and industries reliant on natural resource use, to be a global leader in many of these areas.

[13] For more discussion of these ideas, and the distinction between weak and strong sustainability, see: Heal, G. 2012. "Reflections – Defining and Measuring Sustainability." Review of Environmental Economics and Policy, 6: 147-163.
[14] R Dobbs et al. "Resource Revolution: Meeting the world's energy, materials, food and water needs". 2011, McKinsey Global Institute. http://www.mckinsey.com/insights/energy_resources_materials/resource_revolution

Focus on Forestry: *Canada's Forestry Sector*

Canada's forests are a form of natural capital that provides a flow of value to humans through the timber and other natural resources we extract and through the services they provide – forests sustain habitat for biodiversity, store carbon, preserve soils, purify air, moderate climate and provide a place for recreation and of spiritual importance. The value of a forest is much more than the market value of the timber we extract from it.

Canada's forest products sector presents an interesting case study for a number of reasons: including 1) it's a sector of great economic importance to Canada (in 2013, forestry's contribution to GDP was almost $21 billion[15]), 2) the forestry sector has seen significant change recently, in particular during the 2008-09 economic downturn, which offers the potential for interesting analysis and policy relevant findings, 3) related to this change in the sector, new innovations in products and processes are developing so there is an opportunity to continue this analysis in the future in order to track these changes further[16], and 4) the environmental track record of the forestry sector has shown marked improvement recently, which will make for particularly interesting analysis.[17]

[15] Forestry here is defined as forestry and logging, pulp and paper and wood product manufacturing. For more information on the Canadian forestry sector, see the Canadian Forest Service website: https://cfs.nrcan.gc.ca/statsprofile and the website of the Forest Products Association of Canada: www.fpac.ca

[16] Forest Products Association of Canada, 2014, "Pathways to Prosperity for Canada's Forest Products Sector: Vision 2020 Report Card: 2010-2012" Available at: www.fpac.ca/images/uploads/Vision2020_ReportCard_2014.pdf (See pages 4-11 for more information on new products.)

[17] ibid. See pages 12-18 for more information on environmental improvements.

Including the Environment in Economic Metrics: The Potential for New Insights

With so many important decisions made on the basis of economic metrics, and with the great importance of natural capital to our society and economy, it is clear that economic metrics should incorporate measures of natural capital where doing so could provide an additional level of understanding. Neglecting natural capital inputs and ignoring the adverse impacts some economic activities have on natural capital can lead to the inefficient allocation of resources and improper functioning of markets. The consequences of not including natural capital in economic metrics are twofold:

1 Decisions made on the basis of costs, profits and conventional economic measures are not made with full information. Industry organizations, firms and citizens generally do not know (or pay) the full value of the natural capital they use, and as a result may exploit it wastefully (from a social perspective) or allow it to be degraded; and,

2 Government policies targeting economic and/or environmental objectives may not be optimally designed and may not be aligned with one another because they are designed based only on market-based information.

The most widely used measure of economic activity, GDP, has been given reconsideration with the environment in mind; alternate metrics have been proposed, such as the Genuine Progress Indicator and the Gross Happiness Index, among others.[18] At the heart of such initiatives is a desire to see that, if a country or firm were to make efforts to act as a responsible steward of natural capital by ensuring efficient use of natural resources, protection of ecosystems and minimization of pollution, those efforts would be reflected in economic metrics (either in the short-term, long-term, or both).

However, many other economic measures have not been given as much attention. Productivity, a measure of how much we produce with our inputs, is a key measure of how efficient, innovative, and competitive a country, company or sector is. Yet the limitations of conventional productivity metrics in reflecting environmental aspects of the economy have not been given as much consideration.

Productivity as a Key Metric

A key indicator of a firm or nation's economic strength is its productivity, and the rate of growth/decline in key measures of productivity. Conceptually, productivity describes the relationship between the output of economic activity and the use of inputs in the production process.

$$\text{PRODUCTIVITY} = \frac{\text{OUTPUT}}{\text{INPUT}}$$

Output can be a physical measure (e.g., number of widgets produced) but is commonly measured in dollars. Input is the quantity of a one or more input(s), (e.g., labour or capital, or both) and is also commonly measured in dollar value. The greater the ratio between outputs and inputs, the more productive is the firm, sector or economy. This is a measure of productivity at a point in time; often productivity growth is measured.

Total factor productivity or multifactor productivity (MFP) refers to measuring productivity based on all inputs, while partial factor productivity (PFF) refers to measuring productivity based on just one input, such as labour.[19] Countries, firms and sectors that are innovative and invest in more effective use of their capital improve their productivity, grow their economic output, and thus increase their standard of living.

[18] For a discussion of the limitations of GDP and alternate measures of wellbeing, see Heal, G. 2012. "Reflections – Defining and Measuring Sustainability." Review of Environmental Economics and Policy, 6: 147-163.

[19] For more on productivity, see Statistics Canada's "Productivity Accounts" website at http://www.statcan.gc.ca/nea-cen/list-liste/prod-eng.htm

Focus on Forestry: *Productivity in Canada's Forestry Sector*

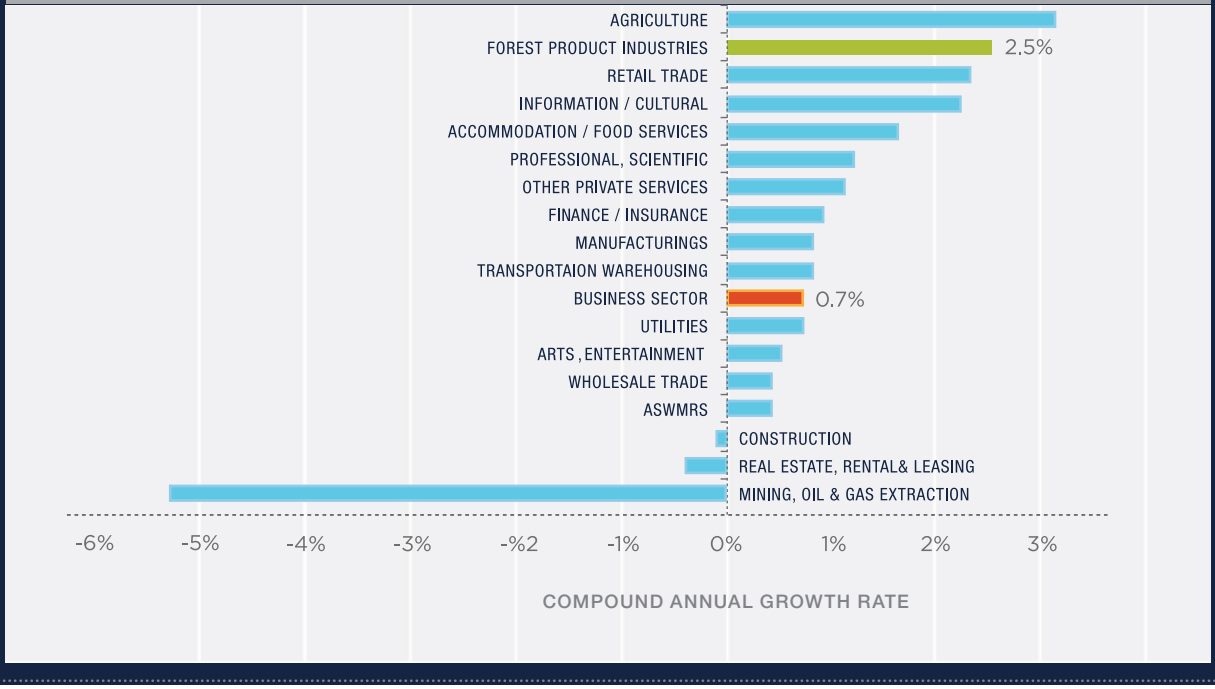
In 2014, the Centre for the Study of Living Standards studied in-depth the conventional measures of productivity for the forestry sector and concluded that the Canadian forest products sector has had an above-average productivity performance in the 2000-2012 period, second only to agriculture in terms of productivity growth among Canadian business sectors. This was attributed primarily to the wood product manufacturing subsector and "while the forestry and logging subsector has also benefited from strong productivity gains, the productivity performance of the paper manufacturing subsector has been far from impressive, especially in the post-2008 period." [20]

Overall, improvements in technology seem to have played a major role in driving MFP growth in the Canadian forest products sector. Of particular interest to our project, energy productivity, defined as the ratio between real gross output and an index of energy input use, has improved substantially in all three forestry subsectors. The report recommends renewed focus on human and physical capital investment, and on research and development spending, in order to maintain the robust productivity growth necessary for the Canadian forest products to remain competitive internationally.

FIGURE 3

INDUSTRY BUILDING ON ITS STRONG PRODUCTIVITY RECORD

Labour Productivity Growth in the Forest Products Sector, 2000-2012



[20] de Avillez, R. "A Detailed Analysis of Productivity Trends in the Canadian Forest Products Sector." Centre for the Study of Living Standards, CSLS Research Report 2014-01, May 2014, available at: http://www.csls.ca/reports/csls2014-01.pdf

Without doubt, productivity metrics matter – they are used to benchmark the economic performance of countries, sectors, firms and facilities against their competitors. While productivity is indeed important, there is a need to understand what insights it does – and does not -- provide about our economic performance. **Six key points provide context on productivity measurement:**

1. There is not one measure of productivity, but a suite of measures. Partial productivity (and in particular, labour productivity) and multifactor productivity measures are the two most common metrics of productivity. Together, they provide more insight than either one considered solely.

2. There are different techniques for measurement; productivity can be measured as either a ratio of physical amounts of outputs to inputs (e.g., widgets per worker-hour) or in ratios of values of outputs to inputs (e.g., dollar value of widgets per hourly wage). In the calculation, values and weights are used, making the choice of prices and price indexes an area of potential debate. To calculate productivity growth rates, nominal values need to be adjusted to real values. Depreciation rates must be calculated for capital stocks, and more. Final calculations can be sensitive to the techniques and assumptions used. Productivity can be measured as a ratio at a point in time, but more commonly productivity growth is measured, leading to potential misinterpretation if the language used to describe the metric is not clear.

3. Tracking productivity can be a useful way of gauging if activity is becoming more efficient or innovative but it does not provide any insight into what practices or technologies are leading to the efficiencies and innovation. As the OECD points out, "Growth accounting and productivity measurement identify the relative importance of different proximate sources of growth. At the same time, they have to be complemented by institutional, historical and case studies if one wants to explore the underlying causes of growth, innovation and productivity change."[21]

4. Productivity does not provide an indication of whether or not the goods and service produced by a company or country are the ones society wants or needs most. It is a measure of how much is being produced with the input(s) used, but provides no insight on whether or not they are the optimal things to produce.[22]

5. Productivity measurement works well when inputs and outputs can be quantified and valued. Two conditions must be met for this to occur. The first is that the outputs and inputs must be measurable (for example, productivity is more easily measured on a farm where tonnes of grain is a relatively easy output to quantify, than it is at a university where quality education of post-secondary students is less easily measured). The second is that data must be available. This can be a particular challenge in firm-level analysis of productivity, as many firms do not wish to make accessible their confidential data on production levels, inputs and costs.

6. Productivity only measures the things our statistical systems measure – meaning natural capital is not generally included. While it is inherently understood that natural capital is important to the functioning of economies and to humans' standards of living, unless natural assets are explicitly bought and sold, their value is generally not accounted for within conventional economic measures. Similarly, economic measures largely do not account for degradation of natural ecosystems due to economic activity and many ecosystem services, like a stable climate, erosion control and air purification, are not valued at all. As Bleishwitz summarizes: "conventional measurement concepts do not explicitly account for the state of natural resources or environmental services."[23]

[21] OECD Manual "Measuring Productivity: Measurement of Aggregate and Industry-level Productivity Growth" 2001. Available at http://www.oecd.org/std/productivity-stats/2352458.pdf

[22] While economists traditionally assume that consumer sovereignty ensures the right mix of goods and services is produced, the conditions under which consumer sovereignty would occur are not always found in modern markets.

[23] Bleischwitz, R. 2001. "Rethinking Productivity: Why has Productivity Focussed on Labour Instead of Natural Resources?" Environmental and Resource Economics, 19: 23-36.

Of the six points related to conventional productivity measurement noted above, it is primarily the final one that we address through this research project – the failure to account for unpriced, non-market inputs and outputs, specifically natural capital use and its appreciation or depreciation. This raises an important question, with large implications for public policy -- **If Canada (or any country, region, sector or firm) were to do a better job managing its natural capital, how would the dividends be reflected in productivity measures?** Currently, efforts to act as stewards of the asset – thoughtfully managing its use and ensuring its value is sustained – will largely not be reflected in the productivity metrics we calculate.

"To judge the success of environmental policies, GDP is too narrow an output measure and asking what happened to traditional MFP growth is in a way asking the wrong question."

– OECD[24]

To fill that shortcoming of conventional productivity measurement, a series of additional productivity metrics that have been adjusted to include the environment is needed. Besco refers to this field of study as green productivity, where "green productivity research considers the flows of natural capital in production processes as well as adjustments to productivity measures so they are more inclusive of the impacts of currently unaccounted for outputs of pollution and waste."[25]

This project aims to construct an **environmentally adjusted measure of productivity** generally, applied to the case study of forestry specifically. If Canadians were to use environmentally adjusted measures of productivity, using them to inform decision-making, it is quite likey we would make different decisions – both public and private.

First, growing the evidence base that shows that environmental protection does not necessarily mean productivity declines would help move the ongoing dialogue on environmental protection from "why not to regulate/incent" to "how best to regulate/incent." Broadening perspectives of governments, industry representatives and engaged citizens groups would encourage a more-informed dialogue. There is a robust body of literature[26] on how pollution pricing can drive innovation.[27] The end result of a well-informed discussion would be better environmental and economic policy.

What we mean by "Linking Natural Capital and Productivity"

Exploring the links between natural capital and productivity can provide insight on how our economic activity relies on the flows of goods and services provided by natural capital stocks, and on how pollution and other impacts of economic activity may depreciate the value of these stocks. Creating an environmentally adjusted measure of productivity is a means of deepening our understanding of these linkages. **Environmentally Adjusted Measures of Productivity** incorporate environmental inputs and/or the output of pollution in their calculation.

[24] Brandt, N., P. Schreyer and V. Zipperer (2014), "Productivity Measurement with Natural Capital and Bad Outputs", OECD Economics Department Working Papers, No. 1154, OECD Publishing, Paris.

[25] Besco, L. 2013. "Green Productivity: Clarifying terminology and concepts." International Journal of Sustainable Economy, 6(4): 406.

[26] A summary of the literature is provided in: Martin, R., and Kemper, A., 2010 "Carbon Pricing, Innovation and Productivity: Implications for Canadian policy makers," Sustainable Prosperity. Available at http://www.sustainableprosperity.ca/dl216&display

[27] See for instance: Popp, D. 2001. "Pollution Control Innovations and the Clean Air Act of 1990," NBER Working Papers 8593, National Bureau of Economic Research, Inc. and Popp, D. 2006. International innovation and diffusion of air pollution control technologies: the effects of NOx and SO2 regulation in the US, Japan, and Germany. Journal of Environmental Economics and Management, 34 (1), January 2006: 46-71.

Second, as a result of the changes in public policy that could be an expected outcome of the creation of environmentally adjusted productivity metrics, sectors and firms that invest in innovative ways to reduce their environmental footprint while growing their production would be rewarded; through efficiency and innovation they may be able to achieve environmental footprint improvements while growing production. If the changes in public policy placed a price on unpriced inputs, firms would see their scarcity and have an incentive to use them efficiently. Similarly, pricing pollution (and therefore valuing pollution reductions) in policy would give firms and industries "credit" (so to speak)[28] for the environmental improvements their actions have led to, rather than simply capturing the costs of compliance or voluntary action.

Calculating an environmentally adjusted measure of productivity[29] provides an additional layer of insight into a country or company's operations beyond what conventional productivity measurement provides. However, even an environmentally adjusted measure of productivity would not shed light on the ultimate sustainability – economic or environmental – of an industry, country or firm. In order to assess sustainability, other metrics are required, focused on both the stocks of natural capital and the flows of ecosystem goods and services they provide.

[28] If pollution were priced, through mechanisms like cap and trade regimes or offset systems, they could receive credit in the form of financial rewards.

[29] A note on language: While environmentally adjusted productivity is increasingly the term used for this concept, there is no officially agreed-upon term. Besco explores the various terms in use and prefers this term. Similarly, environmental degradation, often measured by the proxy of pollution, can be called different things, including "undesirable output" or "environmental bads." Besco has surveyed the literature's terminologies and favours the term "undesirable outputs" to describe outputs which cause environmental degradation including pollution and waste. In contrast, "desirable outputs" would refer to those outputs that are currently considered in conventional measures of productivity. For more, see Besco, L. 2013. "Green Productivity: Clarifying terminology and concepts." International Journal of Sustainable Economy, 6(4): 406.

Focus on Forestry: *Environmental Stewardship, Innovation and Competitiveness in Canada's Forest Products Sector*

Over the past few decades, Canada's forest product sector has invested in reducing its environmental footprint – for instance, increasing the amount of waste diverted to productive purposes, switching to lower-emitting forms of energy and reducing releases of pollutants to water. Most recently, in 2010, the Forest Products Association of Canada's members set ambitious goals for environmental improvement by 2020 with a set of 12 performance indicators being used to track the industry's overall environmental footprint.[30] The first 2 years of progress found a 6% decreased in environmental footprint, with notable success in indicators such as waste going to landfill, energy use and SOx emissions.

Efforts have also focused on ensuring forest management practices support the ongoing health and sustainability of forests, enabling forests to continue to provide habitat for species, ecosystem services (like air purification and flood control), and a flow of timber and other forest products. Sustainability of forest management practices can be assured via independent forest certification, which provides a stamp of approval showing customers they are buying products that come from forests managed to comprehensive environmental, social, and economic standards. Canada has 158 million hectares of certified forests (representing 43% of the world's certified forests), the most in the world.[31]

These innovations can have positive impacts on the health of the forest stock and may help maintain its assets value, which in turn may lead to an overall positive effect on the productivity and competitiveness of individual firms and the sector as a whole. Applying our broad research question to this sector, "As Canada improves the management of forest assets, will the dividends show up in our productivity measures?"

[30] http://www.fpac.ca/index.php/en/page/environmental-progress
[31] Forest Products Association of Canada, press release, September 8, 2014: http://www.fpac.ca/index.php/en/press-releases-full/canadian-forest-products-industry-underscores-commitment-to-environment

An Environmentally Adjusted Measure of Productivity

There are a number of different ways through which to better understand the links between natural capital and productivity measurement, some of which are briefly noted in ***ANNEX A***. This section explores an environmentally adjusted measure of productivity in more detail.

In its simplest terms, an environmentally adjusted measure of productivity nets environmental damage from the conventional measure of output and adds natural capital inputs to market inputs:

$$\text{PRODUCTIVITY} = \frac{\text{OUTPUT} - \text{DAMAGE}}{\text{MARKET INPUTS} + \text{NATURAL CAPITAL INPUTS}}$$

Both partial productivity and multifactor productivity can be adjusted to reflect damage and natural capital inputs,

though we focus on MFP in this project. For more detail on the calculation of environmentally adjusted MFP, including the interpretation of environmentally adjusted MFP growth rates, refer to ***ANNEX B***.

Due to the difficulty of calculating a value for damage, pollution is often used as a proxy for damage even though it is ultimately the value of the damage resulting from the pollution that we wish to better incorporate in our economic decision-making. Abatement or avoidance costs, or shadow social costs per unit of pollution can be used to provide a better sense of the value of the damage pollution causes. With these values we can calculate the net output of production and productivity.[32] Brandt et al (2014)[33] refer to pollution outputs as "bad outputs" and note that "as bad outputs are the target of environmental policies, a productivity measure that does not take bad outputs into account will underestimate productivity growth, whenever countries devote some inputs to reducing bad outputs, thus improving the environmental impact of their production processes, rather than to increasing the production of goods and services."

The inclusion of natural capital inputs that would otherwise be unpriced includes, for instance, water use that is freely extracted from the environment but is an important contributor to production in many industries. Including these unpriced inputs that flow from natural capital could provide a more inclusive measure of productivity. As Brandt et al. (2013)[34] note, "traditional measures of multi-factor productivity (MFP) growth generally do not recognize natural capital as inputs into the production process. Since productivity growth is measured as the residual between output and input growth, it will pick up the growth in unmeasured inputs." If natural capital inputs are measured separately, their contribution can be better understood.

As Brandt et al (2013)[35] explain: "While income generated through the depletion of natural capital, including e.g. minerals and fossil fuels, is captured in Gross Domestic Product (GDP), the role of natural capital as a factor input is generally ignored in traditional Multi-Factor Productivity (MFP) growth measures. This is because the underlying production function generally includes labour and produced capital as input factors, but not natural capital, although the extraction of subsoil assets contributes an important share to GDP in some countries. Neither MFP nor GDP capture the damage created through by-products of the production process, such as greenhouse gas emissions leading to climate change or pollution threatening human health and the environment."

Environmentally adjusted measures of productivity came about as a defense against allegations that environmental regulations were hurting productivity. Nanere and Fraser point out that current measures of productivity are in a sense, biased. "By counting only the costs of controlling pollution . . . the current approach implies that any environmental protection that raises industrial costs reduces productivity regardless how much larger the damage averted."[36] In essence, MFP may be capturing pollution abatement costs, but not the environmental improvement due to the reduction in pollutants.

The earliest effort to adjust productivity estimates for environmental damage was reported by Pittman in 1983, who included abatement costs as a proxy for damage in order to create an environmentally adjusted productivity index for a sample of pulp and paper mills. Pittman's work has been followed by several other studies that calculated environmentally-adjust MFP, either at the sectoral level or for national economies. Though not an exhaustive list, key studies' findings are summarized in ***TABLE 1***.

[32] For more on the challenges of pricing unpriced environmental goods and "bads", see Anderson et al.
[33] Brandt, N., P. Schreyer and V. Zipperer. 2014. "Productivity Measurement with Natural Capital and Bad Outputs." OECD Economics Department Working Paper, No. 1154.
[34] Brandt, N., P. Schreyer and V. Zipperer. 2013. "Productivity Measurement with Natural Capital." OECD Economics Department Working Paper, No. 1092. http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=STD/CSTAT/WPNA%282013%292&docLanguage=En
[35] Brandt, N., Schreyer, P., and V. Zipperer 2013 "Productivity Measurement with Natural Capital" Organization for Economic Cooperation and Development, Statistics Directorate.
[36] Nanere, Marthin and Iain Fraser (2001) "Total Factor Productivity as a Measure of Weak Sustainability" Australian Agricultural and Resource Economics Society proceedings. Available at http://purl.umn.edu/125797

Table 1: *KEY STUDIES OF ENVIRONMENTALLY ADJUSTED MEASURES OF PRODUCTIVITY*

AUTHORS	SCOPE	TYPE OF ENVIRONMENTAL ADJUSTMENT	FINDINGS
Pittman (1983)	Sectoral (US pulp and paper, includes mill-level data)	Inclusion of pollution (4 air and water pollutants)	The productivity rankings of plants differs when pollutants are included, leading Pittman to conclude that "a measure of productivity which ignores undesirable outputs may yield results which are misleading from a societal point of view."
Conrad & Morrison (1989)[38]	National (US, Canada, West Germany)	MFP including capital expenditure on pollution abatement as a proxy for pollution costs	For a period when environmental regulations were minimal (1960-67), conventional productivity growth measures were approximately the same as an estimate of productivity inclusive of environmental inputs. However, for a period during which many environmental regulations were introduced (1972-80), the conventional measure understated the environment-adjusted measure (annual average rates of 2.2 and 2.4 percent, respectively). [39]
Repetto et al. (1996)[40]	Sectoral (US electricity, pulp and paper and agricultural sectors between 1970-1991)	MFP with estimates for pollution damage	During the years studied, the average productivity growth of the electricity sector was found to decline by an average 0.35% each year. Environmental regulations of the time had been blamed for much of this negative productivity growth. Taking into account improvements in emissions however, Repetto et al's data showed environmentally adjusted productivity in fact averaged a positive 0.38-0.68% per year during the same time period; conventional productivity measurement had failed to account for investments made to reduce emissions. Similar results were found for the pulp and paper and agriculture sectors.
Swinand (1999)[41]	Sectoral data (US agriculture by region)	MFP including pesticide pollution as a negative output	Swinand calculated MFP and an environmentally adjusted measure of MFP for agriculture, using pesticide pollution as an environmental variable. He concluded that when growth in pollution levels exceeded growth in output, environmentally adjusted MFP was less than MFP (and vice versa).
Ball et al. (2005)[42]	Sectoral data (US agriculture sector)	MFP using pesticide pollution as a negative output	Ball et al. found annual productivity growth rates fell from 2.4% to -0.4% during the period 1960-1996 when taking into account the total output of agricultural production including environmental losses.

[37] Pittman, R.W. 1983. "Multilateral Productivity Comparisons with Undesirable Outputs." Economic Journal, 93: 883-891.
[38] Conrad, K. and C.J. Morrison, (1989), "The Impact of Pollution Abatement Investment on Productivity Change: An Empirical Comparison of the U.S., Germany, and Canada," Southern Economic Journal, 55(3): 684-698.
[39] The effects were less pronounced for Canada (a divergence of 0.06) and West Germany (a divergence of 0.14) than for the United States. During the period 1972 to 1980, Canada's environmental regulation was on average much less stringent that that of the United States.
[40] Repetto, R., Rothman, D., Faeth, P., & Austin, D. (1996). Has environmental protection really reduced productivity growth? We need unbiased measures. Washington DC: World Resources Institute.
[41] Swinand, G.P. 1999. From Total Factor Productivity to Total Resource Productivity: Incorporating Trends in Pesticide Pollution into Productivity Growth Measures in U.S. Agriculture. Ph.D diss., Boston College.
[42] Ball, E., R. Färe, S. Grosskopf and O. Zaim. 2005. "Accounting For Externalities in the Measurement of Productivity Growth: The Malmquist Cost Productivity Measure." Structural Change and Economic Dynamics, 16: 374-394.

Table 1: KEY STUDIES OF ENVIRONMENTALLY ADJUSTED MEASURES OF PRODUCTIVITY
CONTINUED

AUTHORS	SCOPE	TYPE OF ENVIRONMENTAL ADJUSTMENT	FINDINGS
Rezek & Perrin (2004) [43]	Sectoral (US Midwest agriculture)	Inclusion of water pollution in MFP	Looking at four different time periods, environmentally adjusted productivity was found to be lower than unadjusted productivity in three periods. The one exception – when environmentally adjusted productivity was found to be higher than unadjusted productivity – coincided with a reduction in pesticide and nitrogen pollution linked to years of environmental efforts and environmental legislation (e.g., the Clean Water Act of 1972 and the Safe Drinking Water Act of 1986.)
Brandt, N., P. Schreyer and V. Zipperer (2014) [44]	National (sample of OECD countries)	MFP adjusted for natural capital use and three pollutants as environmental "bads."	Brandt et al. find that "failing to account for natural capital tends to lead to an underestimation of productivity growth in countries where the use of natural capital in production is declining because of a dwindling natural capital stock." On the flip side, "productivity growth is sometimes overestimated in times of natural resource booms, if natural capital is not taken into account as an input factor." [45]
Brandt, N., P. Schreyer and V. Zipperer (2013) [46]	Sectoral (US pulp and paper, includes mill-level data)	Inclusion of pollution (4 air and water pollutants)	All countries achieved "environmental technological progress in the sense that the growth rate of emissions was lower than GDP growth over the period considered . . .this implies that traditional MFP growth measures underestimate productivity growth, because they do not account for the fact that countries have employed some inputs to reduce emission growth rather than increase GDP growth." With the addition of the pollutants, the correction of the conventional MFP measure for the undesirable outputs is not large – exceeding half a percentage point correction to conventional MFP in only a few cases; for Canada, it was just under 0.5 percentage points.
Harchaoui, Kabrelyan and Smith (2002)	National (Canada, with select sectors)	MFP adjusted fo inclusion of greenhouse gas emissions	The analysis finds that failing to account for greenhouse gas emissions underestimates thea productivity performance of the business sector by 0.13 percentage points over 1981-1996 – a difference of 17 percent.
Hailu & Veeman (3 papers)	Sectoral (Canadian pulp and paper)	MFP adjusted for water pollutants	See sidebar box *"Environmentally adjusted Measures of Productivity in the Canadian Forestry Sector"*

[43] Rezek, J.P. and R.K. Perrin. 2004. "Environmentally Adjusted Agricultural Productivity in the Great Plains." Journal of Agricultural and Resource Economics, 29: 346-369.
[44] Brandt, N., P. Schreyer and V. Zipperer. 2013. "Productivity Measurement with Natural Capital." OECD Economics Department Working Paper, No. 1092.
[45] They also find that "The direction of the adjustment to productivity growth depends on the rate of change of natural capital extraction relative to the rate of change of other inputs."
[46] Brandt, N., P. Schreyer and V. Zipperer. 2014. "Productivity Measurement with Natural Capital and Bad Outputs." OECD Economics Department Working Paper, No. 1154.
[47] They also note a key consideration in interpretation: "The adjustment of productivity growth at the aggregate economy level does not only capture the effect of cleaner technologies, but also structural change towards sectors that are subject to fewer emissions, such as services."

The results of the studies in Table 1 lead to some general conclusions:

- An adjusted productivity measure that accounts for outputs and costs (including environmental damage) is generally lower than the conventional measure when pollution is growing. The opposite is also seen – measured productivity growth is understated in periods when environmental regulations are tightening; when environmental damage is mitigated, the negative impact on society is reduced, and thus environmentally adjusted productivity increases.

- Most studies that include environmental degradation consider only a few pollutants (likely largely due to data limitations). The inclusion of additional pollutants could conceivably increase the divergence between the conventional and environmentally adjusted MFP calculations.

These studies illustrate the distinction between conventional productivity metrics and environmentally adjusted ones – in particular, environmentally adjusted values are required to obtain a complete account of economic growth and the impact of policy on industries and society. As Brandt et al note,[48] an environmentally-adjusted measure of productivity is needed in an analysis of the effect of bad outputs on productivity growth; in the absence of doing so, "the effectiveness of environmental policies in promoting production processes that make more efficient use of the environment will be wrongly assessed."

While there is a need for national, sectoral and firm level analysis, there is particular appeal to sectoral analysis for research that aims to uncover policy implications. It is difficult to understand what drives national metrics without breaking them down further to the sectoral level, where each sector's operating context, challenges and opportunities will differ. Sectoral data can provide a richness that national aggregate economic data lack, combined with consistency in key environmental inputs and outputs (which may vary significantly across sectors). This project's analysis of the forestry sector aims to do just that. Of interest, Brandt et al. (2104)[49] note that additional insights may be gained by looking at industry-level data, noting "while the impact of bad outputs is probably small in services sectors, which contribute the largest share to GDP at least in OECD countries, the impact is likely to be much larger in the electricity sector, in transport, in some industries and in agriculture, depending on the bad output considered."

[48] Brandt, N., P. Schreyer and V. Zipperer. 2013. "Productivity Measurement with Natural Capital." OECD Economics Department Working Paper, No. 1092.
[49] Brandt, N., P. Schreyer and V. Zipperer. 2014. "Productivity Measurement with Natural Capital and Bad Outputs." OECD Economics Department Working Paper, No. 1154.

Focus on Forestry: ***Environmentally Adjusted Measures of Productivity in the Canadian Forestry Sector*** | Existing studies of the pulp and paper sector by Hailu and Veeman[50] covering the period from the 1950s to the 1990s show that conventional productivity measures that ignore water pollutant output(s) – in this case, by not measuring total suspended solids (TSS) and biological oxygen demand (BOD) in water – underestimate productivity growth. The time span of their analysis coincided with regulatory changes that forced firms to invest in reducing pollution levels – a benefit that would not have been captured in conventional productivity measurement. They estimated the impacts through a variety of methods and found in all cases that conventional measures under-reported productivity relative to adjusted measures. Depending on the technique, the difference between the conventional average annual productivity growth rate and the environmentally adjusted one differed by between 0.3 to 1 percentage point.[51]

Hailu and Veeman state it well: "Conventional measures of efficiency and productivity account for marketed outputs and inputs, but ignore changes in by-products or undesirable outputs. Such uneven treatment of marketed commodities and pollutant outputs leads to distortions in our assessment of productivity changes, especially in industries such as agriculture or pulp and paper where progress is based on production processes that have significant environmental impacts."[52]

[50] There are 3 papers by Hailu and Veeman that are particularly relevant to this project:
- Hailu, A. and T.S. Veeman. 2000. "Environmentally Sensitive Productivity Analysis of the Canadian Pulp and Paper Industry, 1959-1994: An Input Distance Function Approach." Journal of Environmental Economics and Management, 40: 251-274.
- Hailu, A. and T.S. Veeman. 2001a. "Non-parametric Productivity Analysis with Undesirable Outputs: An Application to the Canadian Pulp and Paper Industry." Ameri can Journal of Agricultural Economics, 83: 605-616.
- Hailu, A. and T.S. Veeman. 2001b. "Alternative Methods for Environmentally Adjusted Productivity Analysis." Agricultural Economics, 25: 211-218.

[51] This analysis can be found in third Hailu and Veeman paper cited above.

[52] ibid.

Towards Decoupling: Potential Policy Implications and Research Priorities

Intentional measurement and valuation of natural capital – and depreciation of natural capital to reflect use and degradation – underscores the importance of those assets. This in turn encourages thinking about their management in new ways and facilitates better understanding how changes in natural capital can affect economic performance, including productivity. The first step is to create new metrics that are more inclusive of natural capital.

Ultimately, exploring the linkages between natural capital and productivity has the potential to influence public policy so that those who successfully decouple economic activity from environmental impact will be recognized and rewarded.[53] Decoupling can result in broader economic, social and environmental benefits than just those accruing to those directly affected by such policies.[54]

As noted earlier, this paper serves as the foundation and introduction for a two-year project. The project's research findings will be presented in academic papers to be submitted to peer-reviewed journals. The potential policy implications identified through this work will be shared in a final project summary, and are likely to include points such as:

1

There is more to productivity than the current conventional measurement of productivity describes;

2

Including the environment in productivity metrics will likely show a better productivity record for Canada's natural resource industries – at least for those who have made environmental improvements (voluntarily, or due to increasing regulatory stringency) that have not been captured in conventional productivity measurements;

3

The interpretation of natural capital's role in productivity can be more complicated than that of others forms of capital; conventional productivity measures can mask important context about natural capital stocks and flows, and adjusting productivity measures for the environment is a challenging task; and

4

A suite of indicators is needed to help understand the linkages between natural capital and productivity. This suite of indicators likely includes1) environmentally adjusted measures of productivity calculated at sectoral and national levels, 2) the indicators that would result from exploration of the questions identified in ***ANNEX A***, and 3) other metrics not identified in this project as well.

Focus on Forestry:
International Comparisons

This exploration of the linkages between natural capital and productivity raises the question of how Canada's performance compares to that of other jurisdictions. National comparisons, of the type recently calculated by the OECD, show that including even just three pollutants in productivity measurement can add a new dimension to our understanding of productivity – although one that is not consistent across countries. At the industry level, the same question arises, with obvious implications for sustainability, innovation and competitiveness. While the Canadian forest products sector fares well for conventional productivity growth relative to its peers, it is likely that the Canadian forestry sector, with its high proportion of certified forestry operations and track record of environmental improvement, would also fare well against other countries in measures of environmentally adjusted productivity.

[53] For instance, the innovative new bio-plastics being produced in the forest products sector may prove to reduce environmental footprint without sacrificing performance, gaining market share for their producers. Public policies that price carbon could facilitate the adoption of these lower-carbon alternatives.

[54] Brownlee, M and Winstanley, M "Nature, It's in our Business: Select Case Studies in Natural Capital Accounting," Sustainable Prosperity, 2014. Available at http://www.sustainableprosperity.ca/article3942

At the same time, it is expected that a number of big questions – broader than the scope of this project – will be raised during this project, including:

- How do we measure and assess natural capital's role in our productivity? How is our natural capital's potential to provide value influenced by our current economic activity?

- Will the adjusted measurement techniques help us to better measure and understand innovation? Would the calculation of environmentally adjusted measures, which would be expected to capture the impacts of innovations that reduce environmental footprint, encourage further innovation?

- What set of productivity indicators is most useful? What are the key data challenges to prioritize now in order to have better data in the future to facilitate the calculation of those indicators?

- Can environmentally adjusted measures of productivity that include pollution push public policy to acknowledge an economic benefit of pollution abatement? If improvements may cost more to implement than the benefit received by a firm, but are socially optimal, in what ways can pollution abatement be encouraged? And the related question, if pollution is priced and pollution abatement valued, will these values be realized by private actors (for example, through a carbon market)?

- How can we apply the analytical methods developed in this project to other sectors?

- What might we do better, in order to improve both our economic and environmental performance? What policy implications and research areas warrant further consideration?

While these questions will not be fully answered through this project, this project's work will hopefully raise the profile of policy-oriented academic work in this field. There are many different possible questions to be explored further, which together can form a forward-looking research agenda. Given the challenge – and importance – of better understanding the linkages between natural capital and productivity, this field will be of ongoing importance to Canadians.

As noted at the outset of this paper, a key goal of this research project is to develop a strong partnership among the sponsors and participants. Additional project partners are welcome for this phase of research and for future work we hope to see launched.

ANNEX A *ALTERNATE WAYS TO EXPLORE THE LINKAGES BETWEEN NATURAL CAPITAL AND PRODUCTIVITY*

There are numerous ways in which the linkages between natural capital and productivity can be explored. This project focuses on constructing an environmentally adjusted measure of multifactor productivity. Additional possible research questions include:

What is the role of natural capital in multifactor productivity? MFP is a key measure of productivity and natural capital is a key source of inputs for resource wealthy countries like Canada and for key economic sectors, but yet we do not have a good understanding of natural capital's role in MFP because it is captured in the residual, along with everything else not explicitly measured. Assessing natural capital's role in multifactor productivity (sometimes referred to as "unpacking" natural capital in MFP) is a particularly interesting question because we are starting from a point of relatively little understanding. As Olewiler notes: "Multifactor productivity is used as a measure of technological change. It is the growth rate of output minus the growth rate of the inputs weighted by their input shares, where, generally, only two inputs are included — capital and labour. The "unexplained" portion of output growth is generally interpreted as technological change. It would more appropriately be interpreted as disembodied technological change (or a measure of our ignorance) because, as a residual, MFP is telling us what is not explained by the growth rates in measured inputs. But natural capital is also an input into the production of goods and services and is not captured inmost estimates of MFP."[55]

What is the partial productivity of natural resources? In contrast to exploring how natural capital contributes to multifactor productivity, we can alternately consider the productivity of natural capital as a measured input. Exploring partial factor productivity of natural capital asks, "combined with our skilled labour and use of physical capital, what amount of output are we generating per unit of a natural capital input, such as iron, wood, land or water?" This is fairly easily done for renewable and non-renewable resources that are measured and traded in the market, but not done for unpriced/untraded resources or ecosystem services. For priced renewable resources, this is a conventional natural resource productivity calculation. For unpriced or unmeasured resources or ecosystem services, the concept remains the same but as it is not generally calculated, it is far from a conventional measure.

What is the "productivity" of pollution? The creation of pollution (such as production of waste or release of emissions) can be thought of as a requirement of production.[56] As such, it can be considered an input and partial productivity measures can be calculated measuring output as a function of this requirement to pollute (essentially, calculating the level of output associated with a level of pollution.) An increase in such productivity means the economy is generating greater wealth with a reduced need to pollute. For example, the productivity of greenhouse gas emissions would indicate how much output is produced from a given input level of greenhouse gas releases – in this case, an increase in output would indicate an improvement as more economic activity results from the polluting activity.

[55] Olewiler, N. (2002). Natural capital, sustainability and productivity: an exploration of the linkages. In Review of Economic Progress and Social Progress 2002: Towards a Social Understanding of Productivity. Ottawa, Ontario: Centre for the Study of Living Standards & The Institute for Research on Public Policy. Retrieved from http://www.csls.ca/repsp/2/nancyolewiler.pdf

[56] This may not be true in the long run when new technologies are introduced, but in the short-term, many activities cannot be sperated completely from their environmental impact.

ANNEX B *CONSTRUCTING AN ENVIRONMENTALLY ADJUSTED MEASURE OF MULTIFACTOR PRODUCTIVITY*

Multifactor Productivity (MFP) relates the growth rate of output to that of combined inputs; generally, a combination of capital (K) and labour (L), though other inputs can be included as well.[57]

$$\text{MULTIFACTOR PRODUCTIVITY: } \frac{\text{OUTPUT}}{(K,L)}$$

With some simplifying assumptions about the way production occurs, multifactor productivity change can be shown to be equivalent to the growth rate of output that is not accounted for by the growth rates in the individual inputs (weighted by their contribution to production). This residual captures technology change, change in management practices and institutions, measurement errors and changes in any other inputs that are not explicitly measured.

$$\text{THE GROWTH RATE OF MFP} = \text{GROWTH RATE OF OUTPUT} - \text{WEIGHTED GROWTH RATE OF K} - \text{WEIGHTED GROWTH RATE OF L}$$

Just as K and L can be measured as explicit inputs to production, so can natural capital (NK). In that case, it is conceptually straightforward to modify the equations to incorporate NK:

$$\text{MULTIFACTOR PRODUCTIVITY: } \frac{\text{OUTPUT}}{(K,L,NK)}$$

and

$$\text{THE GROWTH RATE OF MFP WITH NATURAL CAPITAL} = \text{GROWTH RATE OF OUTPUT} - \text{WEIGHTED GROWTH RATE OF K} - \text{WEIGHTED GROWTH RATE OF L} - \text{WEIGHTED GROWTH RATE OF NK}$$

While MFP is more comprehensive than partial productivity measures (such as labour productivity) and can, as seen, be extended to include NK inputs explicitly, it does not reflect the fact that some outputs of production are undesirable. In particular, no allowance is typically made to account for the negative externalities associated with pollutants. To allow for this, MFP can be adjusted further to include a measure of output that is net of the damage caused during production. An environmentally adjusted measure of multifactor productivity (EAMFP) is created.

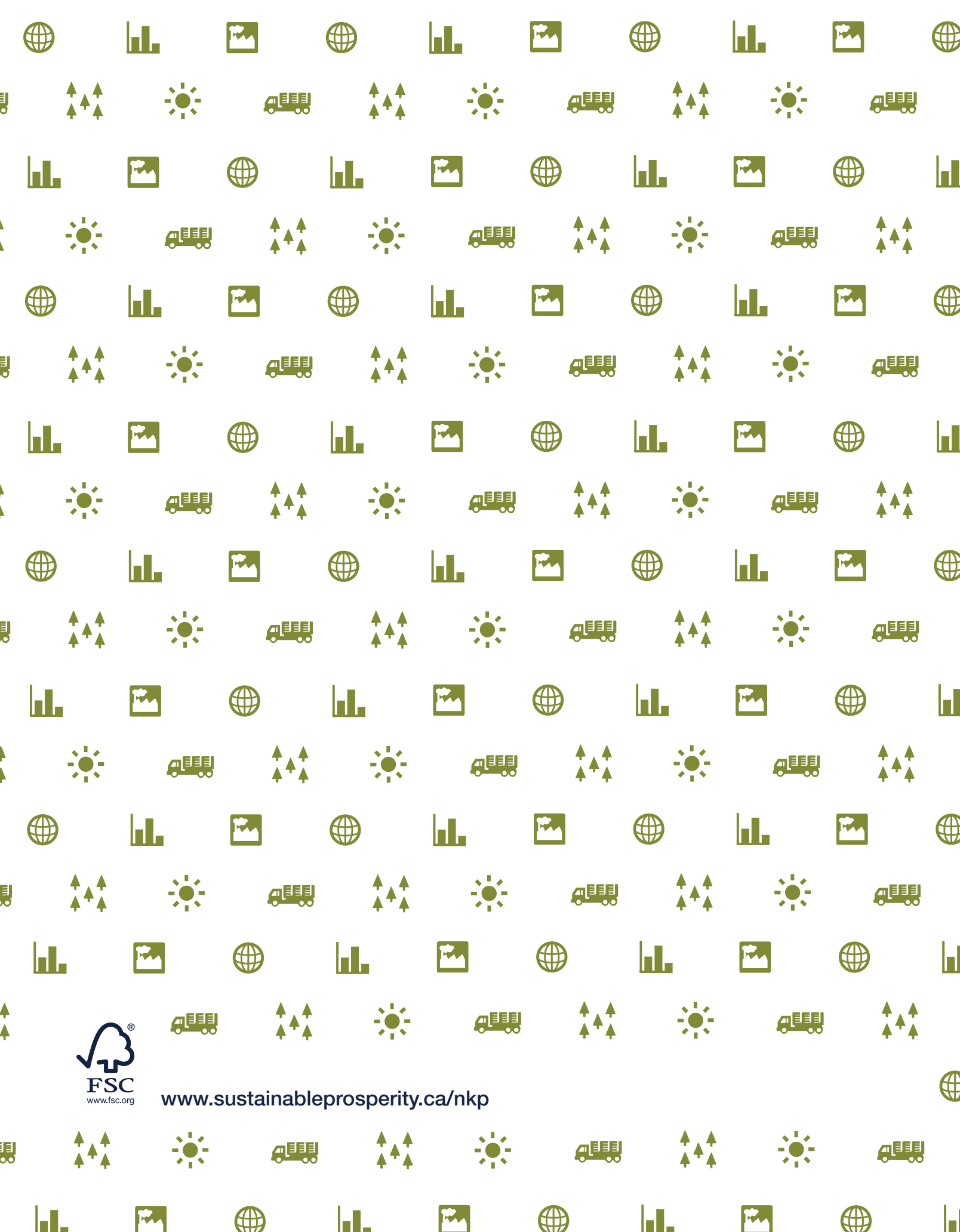
$$\text{ENVIRONMENTALLY ADJUSTED MULTIFACTOR PRODUCTIVITY} : \frac{\text{OUTPUT - DAMAGE}}{(K,L,NK)}$$

The interpretation of EAMFP differs from that of conventional MFP. While the exact interpretation depends on the assumptions made in the model, the growth rate of EAMFP can be shown to be equal to the growth rate of conventional MFP but with adjustments to reflect the differences in the rates of change of NK versus other inputs and differences in the growth rates of output and damages.[58] When damage is created through the production process, and in particular when the growth rate of damage is different than the growth rate of the desired output, MFP and EAMFP are expected to show differing results. Similarly, when natural capital is used as an input, and in particular when its use is growing or declining at a different rate than other inputs, calculations of MFP and EAMFP are expected to provide different values.

[57] Another common specification includes capital (K), labour (L), energy (E), materials (M) and services (S) as inputs.

[58] For more on the derivation of EAMFP, refer to:

- Brandt, N., P. Schreyer and V. Zipperer. 2013. "Productivity Measurement with Natural Capital." OECD Economics Department Working Paper, No. 1092.
- Brandt, N., P. Schreyer and V. Zipperer. 2014. "Productivity Measurement with Natural Capital and Bad Outputs." OECD Economics Department Working Paper, No. 1154.



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