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Integrating Natural Capital in the Canadian Productivity Accounts*

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Abstract : The productivity series for the mining sector reported by statistical agencies usually indicate either a negative or, at best, a lacklustre multifactor productivity growth. This performance, at odd with the anecdotal evidence on the dynamic nature of this sector, is the result of an inadequate production framework employed by the statistical system. This paper proposes an integration between the productivity accounts and the environment satellite accounts which allows for a production framework with the following desirable features: a) It accurately delineates the mining sector in terms of extractive and exploration and development activities; b) It provides a symmetric treatment between produced and natural capital for the extraction activity, and c) It significantly improves the measurement of the real output of the exploration and development activity. Under this alternative framework, the mining sector's multifactor productivity grew annually 3.8% over the 1981-2000 period, compared to no productivity gain for the official figures. As a result, the mining sector now reports the second most rapid multifactor productivity growth of the entire business sector, after that of computers industry. While this revision is substantial, it still remains conservative since the deterioration in the quality of natural capital is not accounted for.

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I. Introduction

The integration of natural capital in the System of National Accounts (SNA) to adequately account for sustainable development has made significant progress over the last decade.[1] This progress is reflected in the inception of a satellite account that accounts for the volume and the value of natural resources to arrive at the notion of extended national wealth. Similarly, natural resources royalties, once considered as a dummy industry in the input-output tables, are now appropriately considered as part of capital compensation.' Under this new treatment of royalties, recommended by the 1993 SNA, produced capital and natural capital are both considered as primary inputs whose compensation is reflected in 'other operating surplus' of the input-output tables.

Despite the integration between the Canadian Productivity Accounts (CPA) and the Canadian System of National Accounts (CSNA), the recent efforts towards more integration of natural capital in the CSNA have, however, had only a mitigated impact on the CPA. As a result, the current treatment of the mining sector in the CPA still overlooks the contribution of natural capital to capital input, making the underlying production framework of this sector inadequate for measurement of multifactor productivity performance. Although natural capital represents about 32% of total tangible capital stock of the mining sector, the CPA assume that this sector makes use of a production function similar to that of any goods-producing industry. This results in an unreliable measure of multifactor productivity growth that, unfortunately, gives rise to some widespread misconceptions about the mining sector. This sector is generally considered stodgy with mature and stagnant technologies, where costs do not decline as in the newer, high technology industries.

Yet, the literature on extractive industries has long advocated the importance of accounting for natural capital in the production framework (Halvorsen and Smith 1984, 1991). Lasserre and Ouellette (1991) have pursued in the same vein and quantified the importance of natural capital in the productivity performance of asbestos in Canada. Using the asbestos as an example, Lasserre and Ouellette (1988) have shown not only the importance of natural capital but also its quality change to accurately measure of productivity growth in mining industries. Since the seminal contribution of Arrow and Wan (1976), quality change has always been a central issue in the literature on management of exhaustible resources. Unfortunately, the contribution of Lasserre and Ouellette (1988) is one of the few attempts that provided an empirical

[1] In this paper, natural capital is used in a generic sense; it refers to subsoil assets.

account of the importance of quality change in the measurement of productivity in the mining sector.

More recently, in an effort to integrate natural resources in the measurement of productivity in the mining sector, Diaz and Harchaoui (1997) have proposed a production framework that accommodates natural capital. Applied to the oil and gas industry extraction activity, this alternate framework provided a 1% growth of multifactor productivity, compared with a significant productivity downward trend over the 1961-1988 period obtained under the existing framework.

This paper is part of the recent efforts initiated by Statistics Canada to establish a research program on eco-efficiency. It extends in many important respects the framework initially proposed in Diaz and Harchaoui (1997).

First, we propose a framework for the integration between the CPA and natural capital assets of the environment satellite accounts (ESA). This contrasts markedly with the framework proposed by Diaz and Harchaoui which provides an integration of mineral reserves stock to the productivity framework without a consideration of the progress accomplished by the ESA. In particular, we exploit the data on the value and volume of mineral reserves developed by the ESA for the entire mining sector. The information available from the ESA, along with detailed data on produced capital at the asset level for the mining sector, allow us to propose a more accurate delineation of the mining sector in terms of exploration and development activity and extraction activity. As a by-product, we also revisit the measurement of real output of the former and propose a deflator more adequate to productivity measurement.

Produced capital and natural capital are then aggregated in a way that is consistent with modern capital theory. This important line of research emphasized that a simple measure of capital stock is not the appropriate measure of capital for a productivity measurement since the wide array of heterogeneous assets have different productive characteristics. In particular, we introduce the notion of extended capital input which recognizes that tangible assets, purchased for the same number of dollars, have different service lives, depreciation rates, tax treatments, and ultimately different marginal products.

Taken altogether, these improvements gave rise to a 3.8% increase in multifactor productivity for the mining sector during the 1981-2000 period, compared to a modest 0.6% increase for the official measure. To a large extent, this upward revision reflects the benefits ascribed to the integration between the CPA and the ESA. Moreover, these results accord with the anecdotal evidence on the dynamic nature of the mining sector, where the successful firms aggressively pursue new technologies and other cost-reducing innovations. Costs over the longer term have fallen substantially--indeed, more than the production costs of non-extractable goods--despite the increasing need to exploit lower grade, more remote, and more difficult to process deposits (Barnett and Morse, 1963; Tietenberg, 1996, chapter 13).

The remainder of the paper is organized as follows. Section II provides some background on the treatment of natural capital in the ESA. Section III first describes the official production framework for the mining sector employed in the CPA. It then introduces the alternative framework and quantifies its impact on multifactor productivity growth. A summary of the finding and possible extensions to the present paper are discussed in the conclusion.

II. Natural Capital in the System of National Accounts

'Measuring' natural capital is a complex task. Measurement is needed, however, to determine whether the quality and quantity of Canada's natural capital assets are improving or declining, and how they impact on productivity performance of this sector. A key part of the challenge is to define and determine exactly what features and natural capital are of interest and how these might be integrated into the CPA.

This section provides a discussion of the main measurement framework (the System of National Accounts (SNA) covering gross domestic product (GDP), and the national balance sheet) and its extension into natural resource accounting. Many aspects of natural capital are not part of the market economy, but much work has gone into developing methods which can translate them into monetary terms (see Cairns 2000).

1. Natural Resources and the Core Accounts

The CPA constitute a set of accounts integrated to the SNA that produce measures of outputs and inputs in current and chained-volume dollars and a variety of productivity measures for the aggregate business sector and its constituent industries (see Baldwin and Harchaoui, 2004). To what extent is natural capital reflected in the SNA? The answer to this question is important as it sheds some light on the extent and the nature of the gap that affects the integration between the existing CPA and natural capital.

While natural capital clearly provides services to the economy, these are often provided at no cost or are implicit in the value of goods and services rather than in explicit transactions. Natural capital assets are often not controlled by economic agents because of their physical nature, or in some cases are so plentiful that they have a zero price. For this reason, the valuation of natural capital flows and stocks is fraught with conceptual and practical difficulties. Nevertheless, international research has been proceeding over a number of years and substantial progress has been made in accounting for natural capital in the SNA, although there is still limited experience in reflecting natural capital in the productivity accounts (see Diaz and Harchaoui 1997 for a discussion).

The transaction accounts of the CSNA measure production, incomes, consumption, capital and financial flows during the accounting period. GDP is the most readily identifiable statistic from the national accounts. Of most interest in the context of environmental accounting is the way natural capital assets are used in the production process to produce goods and services for consumption, capital investment or export. However, the services provided by these assets are often either implicit in the values for other items or they are excluded as they are costed at zero price.

Where there are explicit rents for the use of natural assets, they are shown in the item 'rent on natural assets' in the sector income accounts. The general government sector received $**2.6** billion in resource rents in 2000 (mainly from petroleum, mining and forestry royalties). Many natural assets (e.g. land) are used by their owners for which there is no money transaction.

The value of the services provided by natural capital is implicit in the value of the output of the mining sector. For example, value added reflects the input of labour and produced capital, as well as natural capital.

The value of new additions to natural capital assets such as discoveries of subsoil assets or natural growth in timber are not included as income or GDP. However, the cost of mineral exploration is regarded as fixed capital formation, and is reflected in GDP as the creation of an asset.

In contrast, no deduction is made from income for the depletion or degradation of the natural capital. Thus:

> *"...a country could exhaust its mineral resources, cut down its forests, erode its soil, pollute its aquifers, and hunt its wildlife to extinction, but measured income would not be affected as these assets disappeared" (Repetto et al, 1989).*

The national accounts have a wide range of potential uses for policy making and economic and social research, and thus it is unlikely that the core accounts will be able to meet all possible objectives. In recognition of this, satellite accounts allow for a more flexible approach by providing frameworks that are linked to the national accounts, but focusing on a certain aspect of economic activity. Satellite accounts also allow for standard concepts to be varied to suit particular themes within the context of the national accounts.

2. The Satellite Account

This section begins by looking at the economic statistics frameworks used in Canada, and how they are being extended to cover natural capital issues. Statistics Canada (1997) discusses in depth the extension of the Canada national accounting framework to account for the environment at an economy-wide level.

The statistical framework for economic statistics is well developed, and this framework is used to measure output (as summarised by GDP) and wealth (as summarised in the National Balance Sheet). The international standard is *System of National Accounts 1993* (SNA93) (Commission of the European Communities et al. 1993). The statistical links between the economy and the environment are being increasingly well defined. The international standard is *System of Integrated Economic and Environmental Accounting 2002* (SEEA) **(United Nations Statistical Commission 2002)**. SEEA describes techniques for:

- accounting for the stocks and flows of natural resources;
- accounting for other environment-related transactions (such as expenditures related to protecting the environment and managing natural resources)
- analysing the components of eco-efficiency improvements.

Issues related (but not limited) to depletion of natural capital, degradation of the physical environment and the linkages between economic growth and environmental impacts can be looked at using SEEA. Since it uses the same framework as economic statistics, it is also possible to assess the environmental impacts of economic activity and to develop eco-efficiency indicators—the efficiency with which economic activity employs the environment as a free or cheap input.

SEEA accounts for environmental goods and services that are not part of the market economy. Neither GDP nor the National Balance Sheet seek to measure environmental goods and services which are not transacted. Nor do statistical agencies normally adjust the national accounts data to include those measures. The core SNA by and large deals with the market economy, and where possible it uses market values (or valuations which seek to approximate market values).

2.1. Concepts

How is natural capital reflected in the System of National Accounts? The national balance sheet accounts record the value of natural capital assets that are defined as being within the scope of the system of national accounts-known as the asset boundary. For an asset to be included within the asset boundary of the national accounts it must have an identifiable owner, and the owner must be able to derive an economic benefit from the use of the asset. Assets included are those termed natural capital assets such as subsoil assets, land, forests, water, and fish stocks in open seas that are under the control of an economic agent (often the government).

Natural capital assets such as atmospheric and terrestrial ecosystems are outside the scope of economic assets as they do not have an identifiable owner who can derive an economic benefit from their use. This is not to suggest that these assets are of no value. On the contrary, many of them are essential to life itself. However, even if they fell within the definition of an economic asset, the valuation techniques available to measure such assets tend to be arbitrary and controversial.

Depletion is defined in the SNA93 as the

> *"...reduction in the value of deposits of subsoil assets as a result of the physical removal and using up of the assets, ... the depletion of water resources, and the depletion of natural forests, fish stocks in the open seas and other non-cultivated biological resources as a result of harvesting, forest clearance, or other use." (SNA93, 12.29 and 12.30).*

Depletion in an economic sense results because the value of natural capital stock has been lowered through its use in a productive activity, and the use has reduced the asset's ability to produce an income stream in the future. In this sense depletion is analogous to depreciation of produced assets whereby the current value of the stock of fixed assets declines from normal use.

Physical depletion may not necessarily equate to economic depletion in cases where asset values are low or the resource life is long. While the physical dimension of depletion can be fairly readily observed in practice, its value cannot. This is because the mineral or other natural resource product is not what is being valued-rather it is the decline in the value of the mineral asset below the ground or of the standing timber in the forest. Generally, one has to resort to capital theory to undertake this valuation. In capital theory the value of depletion is a derivative of the amount of the resource extracted and the resource rent.

The resource rent is the value of the flow of capital services provided by a natural capital asset. It is calculated as the value of the output of the natural resource production (e.g. coal, oil) after the intermediate expenses, returns to labour (wages), returns to produced capital (profits accruing from the use of produced capital), and returns to government (taxes) have been removed. Algebraically, the resource rent is represented as:

$$rent_t = (p_t - c_t)q_t$$

where p, c and q represent, respectively, unit price, unit cost (includes wages, intermediate costs, normal return to produced capital and taxes) and quantity extracted.

The resource rent in each period is discounted to derive the net present value of the natural asset:

$$V_t = \sum_{t=1}^{N} \frac{rent_t}{(1+r)^N}$$

where V_t, r_t and N represent, respectively, the value of natural capital asset, the discount rate and the asset length of life.

Depletion D_t can be shown to be equal to the resource rent in the year minus a return (income) on the natural capital asset:

$$\begin{aligned} D_t &= V_{t-1} - V_t \\ &= rent - rV_t \end{aligned}$$

Where the total stocks of an asset are unknown, discoveries of new stocks of subsoil assets or growth in biological assets may increase the stock of a resource so that the level of currently exploitable reserves from which the economic valuation is derived is rising rather than falling. How to account for additions is a vexing issue. In the national accounts, the value of mineral exploration is included as a separate produced asset and is therefore in income and GDP. It could be argued that this should be replaced with the actual value of discoveries.

Subsoil assets are considered to be economic when they have a high geological assurance, extraction is expected to be profitable at the prevailing price and technology, and when they are owned by an economic entity (usually the government). In the ESA economic demonstrated resources include both proven and probable reserves.

Although SNA93 recommends that assets should be valued at their current market price, for many natural capital assets it is not possible to observe the market price directly as there is little trading of undeveloped stocks in the marketplace. The next best method is to value assets as the net present value of the future expected earnings which is theoretically equivalent to the market value. This is the approach that has been adopted in the national balance sheet and in deriving estimates of the value of depletion and additions to subsoil assets presented below.

On the whole, the valuation method used by the ESA is relatively parsimonious, and therefore the data requirements are not unduly burdensome. For quantity data, only reserves are considered, so the quantities of mineral stocks are easy to obtain. Most of the data required for valuation under the proposed method either is already used by Statistics Canada in the construction of the System of National Accounts or are publicly available or available at a modest cost from private sources. Constructing the accounts for subsoil minerals, therefore, required no independent data collection or survey by Statistics Canada. Nevertheless, there is no single consolidated source for the data needed, and considerable effort was expended by the ESA staff in collecting the data.

A major problem with most accounting approaches is that they assume all reserves are homogeneous in terms of grade and costs. For example, under the Hotelling valuation principle, average extraction cost should be calculated as the average cost of extraction from all reserve classes. In practice, most techniques use the extraction cost of currently extracted reserves. The reality is that a nation's reserves are not all in one cost class. It has already been noted that reserves are likely to exist in a number of classes, ranging from high quality (low cost) to low quality (high cost). Resource accounting, such as that in the current IEESA, generally treats the entire national stock as one heterogeneous deposit whose value is calculated by multiplying the average unit value of that reserve by the quantity of the reserve.

In principle, the heterogeneity problem could be overcome by calculating reserve values for each reserve class and then aggregating across reserve classes. This approach is likely to be quite costly, and extraction data may not be available for all reserve classes, particularly those not yet being exploited. However, since these disaggregated calculations are not undertaken by the ESA, its estimated values for the total reserve stock are likely to be too high for many of the minerals.

2.2. The Value of Natural Capital Assets

There is a well developed literature in economics and accounting with regard to the appropriate treatment of mineral resources. The major difficulty for the national accounts has been the lack of adequate data on the quantities and transaction prices of mineral resources. Unlike new capital goods such as houses or computers, additions to mineral reserves are not generally reflected in market transactions, but are determined from internal and often proprietary data on mineral resources. Moreover, there are insufficient data on the transactions of mineral resources, and because these resources are quite heterogeneous, extrapolating from existing transactions to the universe of reserves or resources is questionable. Notwithstanding these difficulties, Statistics Canada has developed an Environmental satellite Accounts where natural capital, defined here to include subsoil fuel minerals (petroleum, natural gas, and coal) and other minerals (uranium, iron ore, copper, lead, zinc, gold, silver, molybdenum, phosphate rock, sulphur, boron, diatomite, gypsum, and potash).

Natural capital assets on the Canadian balance sheet accounts are land, subsoil assets and timber. Land valuations are available through administrative sources, and net present value techniques (which take into account current production rates, prices, costs, and discount rates) are used to value both natural capital assets. Plantation standing timber could also be considered a natural capital asset and plantations are included in the balance sheet as inventories because timber growth is controlled. Water and fish stocks have not been included on the Canadian national balance sheet due to a lack of available data.

Table 1. Canada's Total Assets, Current Prices

	1981		**1988**		**2000**	
	$M	**%**	**$M**	**%**	**$M**	**%**
Tangible assets	1,743,066	100.0	2,488,616	100.0	4,270,582	100.0
Selected produced assets	1,054,645	60.5	1,673,287	67.2	2,702,383	63.3
Residential structures	288,954	27.4	527,764	31.5	911,833	33.7
Non-residential structures	426,378	40.4	616,424	36.8	914,726	33.8
Machinery and equipment	131,506	12.5	217,782	13.0	389,140	14.4
Consumer durable goods	109,058	10.3	184,807	11.0	292,352	10.8
Inventories	98,749	9.4	126,510	7.6	194,332	7.2
Selected non-produced assets	688,421	39.5	815,329	32.8	1,568,199	36.7

Source: Statistics Canada, Cansim Table 378-0005 - National balance sheet, national wealth accounts, annual.

The Canadian national balance sheet recorded $4.3 trillion worth of tangible assets in 2000, of which $1,6 trillion (36.7%) were non-produced assets. The latter include land, timber and subsoil resource stocks.

Table 2. Canada's Natural Capital Assets, Current Prices

	1981		1988		2000	
	$M	**%**	**$M**	**%**	**$M**	**%**
Selected non-produced assets	688,421	100.0	815,329	100.0	1,568,199	100.0
Land	312,110	45.3	466,777	57.3	855,601	54.6
Timber	86,261	12.5	141,706	17.4	260,925	16.6
Subsoil resource stocks	290,050	42.1	206,846	25.4	451,673	28.8
Selected energy resources	205,451	70.8	105,439	51.0	366,289	81.1
Selected metallic minerals	66,696	23.0	85,223	41.2	56,986	12.6
Selected non-metallic minerals	17,903	6.2	16,184	7.8	28,398	6.3

Source: Statistics Canada, Cansim Table 378-0005 - National balance sheet, national wealth accounts, annual.

While land accounted for 55% of the value of Canada's non-produced capital assets in 2000, subsoil assets account for 30% and timber account for 16.6% of Canada's economic environmental assets. No values are included for water or fish stocks, or other environmental assets outside the SNA asset boundary.

The value of subsoil assets, or natural capital, in current prices increased by 56% between 1981 and 2000. Much of this growth was due to rising prices. Chain volume estimates of natural capital increased by 50% between 1981 and 2000. The strong volume growth has been due to new discoveries exceeding extractions during this period. The current price growth has been driven by increasing prices in significant minerals such as iron ore, magnesite, crude oil, condensate, and Liquified Petroleum Gas and falling real discount rates.

III. Natural Capital in the Canadian Productivity Accounts

1. The Existing Framework

As indicated in the previous section, significant progress have been accomplished in the account for natural capital in the SNA. Mineral reserves in volume and value are accounted in the ESA that is separate from the core accounts. The CPA are integrated to the SNA but not to the ESA. This lack of integration leads to major anomalies and inaccuracies in the CPA. For example, both exploration and development generate new subsoil mineral assets just as investment creates new produced capital assets. Similarly, the extraction of mineral deposits results in the depletion of subsoil assets just as use and time cause produced capital assets to depreciate. The CPA include the accumulation and depreciation of capital assets, but they do not consider the generation and depletion of subsoil assets. The omission is troubling. Mineral resources, like labour and capital, are basic inputs in the production of many goods and services. The production of mineral resources is no different from the production of consumer goods and capital goods. Therefore, productivity accounts that fail to include mineral assets in the mining sector production framework may seriously misrepresent trends in productivity performance over time.

Current treatment of subsoil assets in the CPA has three major limitations. First, there is no entry for additions to the stock of subsoil assets in the production or asset accounts. This omission is anomalous because businesses expend significant amounts of resources on discovering or proving reserves for future use. Second, there is no entry for the using up of the stock of subsoil assets in the production or asset accounts. When the stock of a valuable resource declines over time through intensive exploitation, this trend should be recognized in the CPA. Third, there is no entry for the contribution of subsoil assets to current production in the production accounts but compensation of natural capital in the form of royalties is part of capital compensation. This inconsistency is partly the reflection of the prevailing wisdom in the official productivity accounts that natural capital constitutes a 'free gift of nature' and not a form of capital.

Table 1. Delineation of the mining sector in the Canadian Productivity Accounts

Industries of the Mining Sector	Percentage of Nominal GDP
Extraction activity	**91.8**
Gold mines	4.2
Other metal mines	12.5
Iron mines	2.1
Asbestos mines	0.6
Other non-metal mines (except coal)	3.3
Salt mines	0.5
Coal mines	3.6
Crude petroleum and natural gas industries	62.7
Quarry and sand pit industries	2.3
Exploration and development activity	**8.2**
Services incidental to mining	8.2
Mining sector	**100.0**

Notes : Business sector GDP; average shares for the the 1981-2000 period.

The integration between the CPA and the ESA constitutes then a necessary condition to the formulation of an adequate production framework for the mining sector. Furthermore, the implementation of this integration in the official CPA is motivated by two additional factors.

First, the relative significant size of the mining sector in the aggregate business sector. With about 6.3% on average during the 1981-2000 period, the mining sector has a similar importance to retail or wholesale trade in the overall business sector. Under the 1980 standard industrial classification, the mining sector covers officially ten industries with different size. The oil and gas industry heads the mining sector with about 3/5 of nominal value added, followed far behind by other metal mines and services incidental to mining (respectively 12,5% et 8,3%) (see Table 1).

These ten industries can be grouped into two major activities: exploration and development, an activity which groups establishments engaged in the discovery of natural resources pools and information about the resource (Quyen, 1991, Fisher, 1978), is covered by services incidental to mining. The remaining nine industries cover extraction activity, which consists of establishments engaged in the management of the inventory of natural reserves stocks and the extraction of natural resources. As it will become clear later, this delineation of the mining sector undercovers the size of the exploration and development activity of the mining sector. A large portion of this activity is not treated as part of the mining sector in the CPA. It is rather assigned to oil and gas facility construction, an industry that is part of the construction sector.

Compensation of capital accounts for about ¾ of the mining sector GDP, reflecting the capital intensity of the underlying technology. As indicated by Table 2, the structure of capital stock of this sector is mainly composed of buildings and engineering construction assets, of which those of the engineering construction of the oil and gas industry accounts for a significant portion. [2] Engineering construction capital of the oil and gas industry is sizable. Under the existing delineation of the mining sector in the CPA described above, this asset is entirely assigned to the extraction activity of this industry, resulting in an overestimation of its capital stock.

[2] Since oil and gas industry accounts for the bulk of the mining sector GDP, it follows that the engineering construction capital stock of this industry constitutes the largest component of the mining sector's capital stock.

Table 2. The asset structure of the mining sector capital stock

Assets Class	Percentage of capital stock in current dollars
Other machinery and equipment	7.9
Information technology	0.1
Buildings and engineering construction	84.5
Inventories	3.3
Land	4.1
All assets	**100.0**

Second, the financial statements of the mining sector indicate that, with about $20 billions of profits, the mining sector is one of the most profitable of the entire business sector in Canada. This stands in a sharp contrast with a lacklustre 0.5% multifactor productivity growth over the 1981-2000 period indicated by the CPA. Capital input is the primary source of real value added growth, followed far behind by multifactor productivity and labour input (table 3).

Table 3. Sources of Real Gross Output Growth in the Mining Sector
(Average percentage points contribution)

	1981-2000	1981-1988	1988-2000
Real gross output	2.9	3.6	2.5
Labour input	0.1	0.1	0.1
Capital input	1.5	2.0	1.3
Intermediate inputs	0.8	0.2	1.2
Multifacor productivity	0.5	1.4	0.0

In summary, under the existing CPA, the mining sector covers the exploration and development activity and the extraction activity. Out of the ten mining industries delineated by the CPA as being part of the mining sector, only one, that is, services incidental to mining, is part of exploration and development activity. The remaining industries belong to extractivity activity. Nowhere is natural capital reflected in the capital input of extraction activity. The underlying technology of this activity is, therefore, assumed to be analogous to that of any other goods-producing sector: capital and labour inputs are efficiently combined to produce a certain amount of output.

There are several problems related to the treatment of the mining sector in the CPA.

First, while the delineation of the extraction activity is adequate, the exploration activity suffers from an undercoverage. Services incidental of mining covers all establishments engaged in the exploration and development of metal and non metal mines. It also covers those performing this activity on a contractual basis for the oil and gas industry. However, the bulk of the exploration and development activity for the oil and gas industry is performed on a own-account basis and it is not reflected in the services incidental to mining. It is rether part of the construction sector under the oild and gas facility construction industry. This delineation stems from the current treatment of own-account industries in the Input-Output Tables (see SNA 93).

Second, and this is related to the first issue, given the ambiguity of the delineation of the activities of the oil and gas industries, all of capital input produced by the CPA for the whole oil and gas industry is in fact assigned only to its constituent extraction activity. This treatment left the other portion of the oil and gas industry, the exploration and development activity, with no capital input at all.

Third, the extraction activity of the mining industry employs produced capital input and labour input to produce a certain amount of output represented by the flow of natural resources extracted from the ground. This industry also uses the services of natural resources reserves stocks, a form of natural capital for which it pays a cost of capital represented by natural resources royalties. While this compensation of natural capital is already part of compensation of capital of the extraction activity, natural capital is not accounted in the capital input of this activity, resulting in a misspecification of the production function that underlies multifactor productivity measures of this activity.

The next section proposes a more accurate delineation of the activities of the mining sector and a specification of a more adequate production framework.

2. An Alternative Production Framework and Its Implications

2.1. An Alternative Delineation of the Mining Sector

Officially, in the CPA, the mining sector covers only the industries listed in Table 1. Two recent sources of information –the ESA and the availability of capital stock by asset categories –led us to reconsider the delineation of the mining sector, to propose a more adequate allocation of capital stock for each of the activities of the mining sector, and to account for natural capital in the capital input of extraction activity.

More specifically, the efforts towards an integration between the ESA and CPA underlined the undercoverage of the mining sector in the CPA (see Table 1). The exploration and development activity of the oil and gas industry is an own-account activity and, given the Input-Output conventions, is part of the construction section under 'oil and gas facility construction.' Moreover, the availability of more detailed information on capital formation by assets class made it possible to assign the various assets of the mining sector to the activities where they belong and to construct a corresponding capital stock following the methodology devised by the CPA (see Harchaoui and Tarkhani 2002).

Table 4. Alternative Delineation of the Mining Sector in the Canadian Productivity Accounts

Industries of the mining sector	Percentage of nominal GDP
Extraction activity	**82.4**
Gold mines	3.6
Other metal mines	10.5
Iron mines	1.9
Asbestos mines	0.5
Other non-metal mines (except coal)	3.0
Salt mines	0.5
Coal mines	3.3
Crude petroleum and natural gas industries	57.0
Quarry and sand pit industries	2.0
Exploration and development activity	**17.6**
Services incidental to mining	9.2
Oil and gas facility construction	8.4
Mining sector	**100.0**

Notes : Business sector GDP; average shares for the 1981-2000 period.

Under the alternative delineation of the mining sector, the coverage of the exploration and development activity, initially represented by the services incidental to mining industry, has been expanded by the size of oil and gas facility construction, the industry that comprises the exploration and development activity of oil and gas industry. The new industry composition of the overall mining sector is shown in Table 4.

The allocation of the various capital assets to the alternative delineation of the mining sector listed in Table 4 has resulted in a shift of a significant portion of engineering construction capital stock from oil and gas extraction activity (i.e. crude petroleum and natural gas) to its exploration and development counterpart (i.e. oil and gas facility construction).[3] The value of natural capital obtained from the ESA, and discussed in section 2.2., were then exploited to construct the capital input of the mining sector's exraction activity and to derive the corresponding multifactor productivity measure.

2.2. The Proposed Production Framework

Conceptually, exploration and development is a different activity from mineral extraction. The outputs of exploration and development are newly discovered deposits or extensions and revisions of existing reserves, all of which add to (or subtract from, for downward revisions) proven reserves (see Soloday 1980). Exploration and development (ED) activity uses capital and labour inputs (K^{ED}, L^{ED}) to produce knowledge of newly-discovered deposits or additional knowledge of already-known deposits. The output of exploration and development activity can be characterized as additions (new discoveries and revisions and extensions) to the inventory of mineral deposits.

However, exploration and development should be clearly distinguished from mineral extraction. Even if additions to the inventory of known mineral deposits are considered to be a product of exploration and development, extractions from the resulting 'inventory' are not the product of mineral extraction but rather depreciation of capital stock that enters as an input into mineral extraction. In addition to capital and labour inputs (K^{E}, L^{E}), extraction (E) activity also uses the services of natural capital (R) to extract natural resources. Natural capital shares similar features as those of produced capital stock. It is derived through a formula analogous to the the perpetual inventory method used for produced capital, that is, $R_t = R_{t-1} + A_t - D_t$ (where A_t and D_t, represent, respectively, discoveries or additions and depletion). Discoveries A_t, produced by the exploration and development activity, and depletion D_t, undertaken by the extraction activity, play, respectively, a similar role to investment and depreciation of produced capital in the perpetual inventory formula. Nominal output of these two activities can be expressed as follows:

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3 Its portion varies from 27.3% in quarry and sand pit industries to 77.4% in coal mines. These assets are : exploration drilling, development drilling, drilling expenditures, pre-mining, research and other costs, geological and geophysical expenditures, minesite exploration, minesite development, exploration and deposit appraisal - off mine sites, drilling and blasting equipment, other computer-assisted process machinery and equipment.

$$V^{ED} = \sum_a u_a^{ED} K_a^{ED} + \sum_s w_s^{ED} K_s^{ED} + \sum_j v_j^{ED} M_j^{ED} \quad (1)$$

$$V^{E} = \sum_a u_a^{E} K_a^{E} + u_R^E R + \sum_s w_s^{E} H_s^{E} + \sum_j v_j^{E} M_j^{E}, \quad (2)$$

where

V^i = Nominal output of activity $i\,(i = ED, E)$;

u_a^i = User cost of capital of produced asset a employed by activity i;

K_a^i = Capital stock of asset a employed by activity i;

u_R^E = User cost of capital of natural capital R employed by the extraction activity E;

R = Natural capital stock employed by by the extraction activity E;

w_s^i = Hourly rate of labour composentation of activity i paid to the worker s;

H_s^i = Hours worked by worker s in activity i;

v_j^i = Price of intermediate inputs j employed by activity i;

M_j^i = Volume of intermediate inputs j employed by activity i.

The alternative production framework characterized by (1) and (2) leaves intact the value of nominal output currently used by the CPA. The structure of the inputs in the extraction activity contrasts, however, with the one employed in the CPA. In addition to the cost of produced capital $\left(\sum_a u_a^E K_a^E\right)$, this activity also incurs the cost of natural capital $\left(u_R^E R\right)$. While the construction of the cost of capital for produced capital is well established in the productivityly literature (see Harchaoui and Tarkhani 2002), this is not the case for natural capital. We suggest two ways to allocate capital compensation of extraction activity $\left(Y^E\right)$ between produced asset K_a^E and natural capital R:

The first approach consists of using the internal rate of return method employed by the CPA and other official productivity programs around the world. Information on produced capital stock K_a^E and its depreciation rate δ_a^E, capital gains π_a^E and the asset price p_a^E is available from the CPA. Similar information on natural capital, that is, $R, \delta_R^E, \pi_R^E, z$ (where z is the price of the natural capital asset) is available from the ESA. The internal rate of return r^E can be endogenously determined as in the conventional CPA:

$$r^E = \frac{Y^E - \sum\left(\delta_a^E - \pi_a^E\right) p_a^E K_a^E - \left(\delta_R^E - \pi_R^E\right) zR}{\sum p_a^E K_a^E + zR} . \quad (3)$$

The second approach is based on the external rate of return method. The extenal rate of return $\hat{r}^E$ is applied to the produced asset a, the rate of return ϕ of natural capital R is then determined residually as follows :

$$\phi = \frac{Y^E - \sum\left(\hat{r}^E + \delta_a^E - \pi_a^E\right) p_a^E K_a^E}{R} . \quad (4)$$

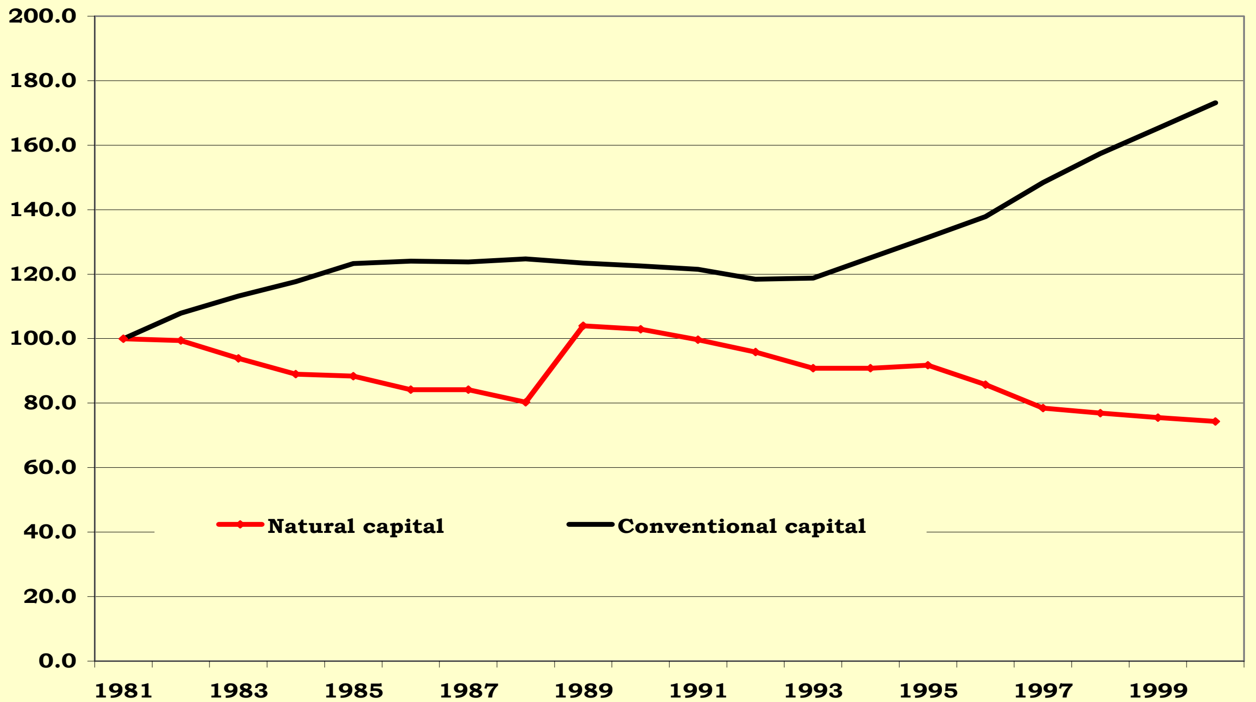
Both approaches are appealing as they propose a rate of return that exhausts the value of capital compensation. The first approach is particularly attractive since it reflects the parallel that exists between for produced capital and natural capital. However, it suffers from a highly volatile rental price for natural capital due to the wild fluctuations of the variables δ_R^E, π_R^E and z. This, in turn, gives rise to productivity estimates with an abnormal degree of volatility. In contrast, the second approach alleviates considerably this shortcoming. Therefore, it constitutes our preferred approach.

2.3. Implications

The proposed production framework of the mining sector is characterized by the following appealing features.

First, it leaves the exisiting nominal production account and, accordingly, the existing integration between the CPA and the SNA in current prices, intact. Second, it improves the integration between the CPA and the most recent component of the SNA, namely, the ESA. The value of natural capital produced by the ESA is combined with the user cost formula to estimate the value of natural capital services, a treatment that is symmetric to the one employed for produced capital services. Figure 1 shows that natural capital services trended downward at an average annual growth rate of -1.5% during the 1981-2000 period, compared to 2.9% increase for tangible capital services. Given the largest share of natural capital in total capital compensation, it follows that the overall capital services for extraction activity declined at -1.6% on average. Third, natural capital accounted for in the CPA is not adjusted for the quality change. As a result, any revision to the multifactor productivity that would result from this new production framework must be considered as a lower bound. Finally, while the real output of the extraction activity is adequate for productivity measurement, this is not the case for that of exploration and development activity. The output deflator is based on the input price of the drilling operations, implying by definition, a lack of productivity gains.

Figure 1. Chained Volume Indexes of Capital Services



There are ways to improve the quality of this deflator and one of them consists of using the shadow price of natural resources discoveries measured by their marginal discovery cost. It has been suggested by Brown and Field (1978) that marginal finding costs provide an estimate of the otherwise unobservable shadow price of discoveries in situ. This result follows from a simple model of optimal exploration and extraction in which there are no depletion effects in the exploration stage. Optimality then requires that exploration be conducted up to the point where the marginal finding cost equals the shadow price of discoveries. Thus, to the extent that the shadow price can be expected to be a good indicator of resource scarcity, marginal finding cost estimates provide valuable information.

The construction of marginal discovery cost assumes the availability of a reasonably long time series on exploration and development expenditures, input prices and the volume of natural resources discoveries. Unfortunately, this kind of information is only available for the oil and gas exploration and development industry.[4] Since the oil and

[4] These data are available in Statistics Handbook produced by the Canadian Association of Petroleum Producers.

gas exploration industry accounts for about 2/3 of the overall exploration and development activity, it follows that the adjustment to the real output series undertaken in this paper can only be considered as a lower bound.

The oil and gas exploration industry is assumed to be competitive in the input markets. No assumptions are made about the structure of output markets. Three inputs, exploration drilling, geophysical effort, and land acquired for exploration drilling are used to produce two outputs, oil discoveries and natural gas discoveries. We assume the the multi-output technology can be represented by the dual cost function

$$C = C\left(w_1, w_2, w_3, Y_o, Y_g, z, D\right) \tag{3}$$

where w_i $(i = 1,2,3)$ are the input prices, Y_o and Y_g, respectively, the oil and gas discoveries, z is cumulative drilling effort and D is a set of time dummy trend variables. This sort of hedonic cost function is linearly homogeneous, increasing, concave, and continuous in the vector of input prices, and increasing in Y_o and Y_g. The inclusion of z in the cost function is to capture the effect of depletion of exploration prospects that occurs in a region. Typically, the largest pools are discovered first, making it often more difficult and therefore more costly to discover subsequent pools. This implies that the cost function is increasing in z.

The system of three equations to be estimated consists of the cost function (3) and the share equations for drilling effort and geophysical effort. An iterative three-stage least square estimation procedure was adopted to avoid the possibility of having inconsistent parameter estimates due to the simultaneity problem that may arise from the output.[5]Then the predicted values of marginal finding costs are calculated by simply differentiating the estimated cost function with respect to the two output variables.

3. Empirical Results

This section discusses the following results : a) the impact of accounting for natural capital input on multifactor productivity growth of the extraction activity; b) the comparative pattern between the existing and proposed output deflators for the oil and gas exploration industry and the quantitative impact on its the multifactor productivity growth; c) the revised multifactor productivity performance of the overall mining sector and its contribution to the aggregate business sector productivity trend.

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[5] The instrument set used for Y_o and Y_g consists of the exogenous variables in the cost model and the current and lagged values for oil and gas reserves produced by the environment satelitte account.

Figure 2 compares the quantitative impact of the alternate production framework on multifactor productivity growth of the extraction activity of the mining sector. Compared to the official production framework, the alternative framework accounted for natural capital services in the overall capital input and shifted exploration drilling produced capital assets from the extraction activity of the oil and gas industry to its exploration and development activity, where they belong.

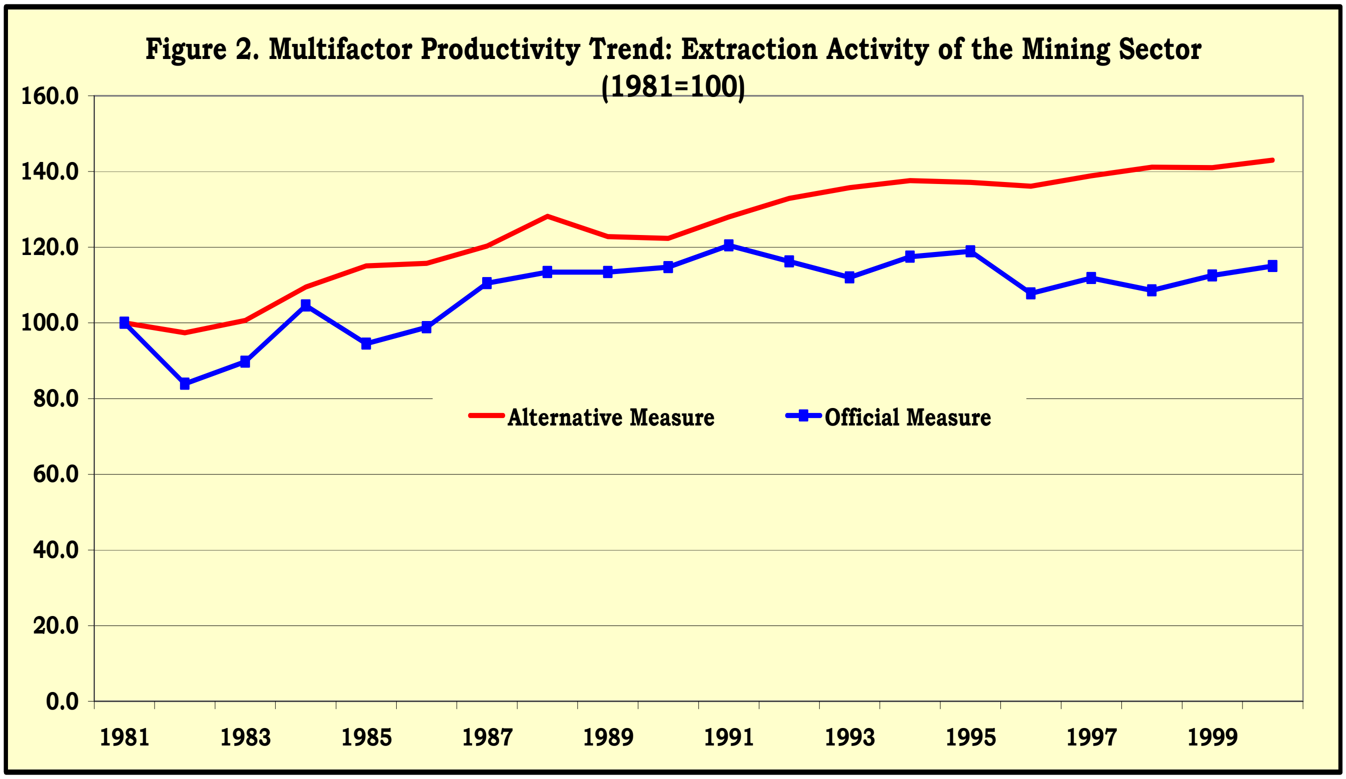


Figure 2. Multifactor Productivity Trend: Extraction Activity of the Mining Sector (1981=100)

Under the alternative production framework, multifactor productivity growth for the extraction activity of the mining sector shows a 1.9% average annual growth over the 1981-2000 period, compared to 0.7% for the official figure. With this revision, the extraction activity of the mining sector then becomes one of the best performing of the entire business sector, ahead of agriculture (1.6%) and even some of the information and communication technology-producing industries such as electronic equipment (1.5%) and communications (1.4%), but far behind computers industry (6.5%).

An important limitation of the proposed production framework stems from an inadequate account for the deterioration in the quality of natural capital stock. Unfortunately, the lack of data on natural resources quality change prevents us from making any type of structured guess on its possible impact on the productivity performance of the extraction activity. Nonetheless, if we assume that the deterioration of the quality observed by Lasserre and Ouellette (1988) for asbestos is pervasive across the entire extraction activity, then the upward revision in extraction activity multifactor productivity growth should be considered as a lower bound.

There is a wide variation in the industrial sources of this upward revision of multifactor productivity growth of the extraction activity (Table 5). Gold mines and asbestos industries have seen their productivity growth considerably revised downward during the 1981-2000 period (from 7.2% to 2% and from 0.1% to -3.1%, respectively). This stands in a sharp contrast with the productivity of oil and gas and coal mines which has been significantly revised upward (from –1.3% to 2.3% and from –6.9% to 2.8%, respectively). The revisions in the multifactor productivity growth of iron mines and quarry and sand pit were, however, much more modest.

Table 5. Industry Sources in the Revision of Extraction Activity Multifactor Productivity Trend, 1981-2000
(average annual growth rates in percentage)

	Alternative measure	Official measure
Gold mines and other metal mines	2.0	7.2
Iron mines, Other non-metal mines and Salt mines	-0.4	-0.7
Asbestos mines	-3.1	0.1
Coal mines	2.8	-6.9
Crude petroleum and natural gas industries	2.3	-1.3
Quarry and sand pit industries	0.9	0.7
Extraction activity of the mining sector	**1.9**	**0.7**

This upward revision in the multifactor productivity gain accords with the technical change that occurred in the extraction activity. In the 1980's, falling coal prices drove many of the small-scale, less efficient mines out of the industry, thereby boosting the average level of productivity. In addition, falling prices forced the industry to become more competitive. Productivity was increased by the adoption of labour saving technologies, such as long-wall mining in underground mines, and cutting by draglines in surface mines (see Darmstadter (1997)). Similarly in the petroleum industry in the 1980s, the fall in petroleum price led to the closure of many high cost wells (that is, depletion of the extensive margin). Technological breakthroughs, which included the development of floating platforms for petroleum extraction in deepwater areas, techniques to drill horizontally into petroleum deposits and tar sands, further increased productivity and mitigated the fall in output (see Bohi (1997)). As discussed in Tilton (1997), the story of the copper industry over the last 25 years is one of remarkable recovery from being on the brink of collapse. Falling product prices had not led to the closure of loss-making mines or reductions in wages but in the early 1980's everything changed and the whole industry was restructured. This led to a dramatic "shake out" of small scale, less efficient mines, and consolidation into a fewer number of larger, more efficient mines. In addition, there has been significant technological innovation over the last 15 years, for example the development of new chemical processes for extracting copper from copper ore (see Tilton (1997)), and processes for copper recycling.

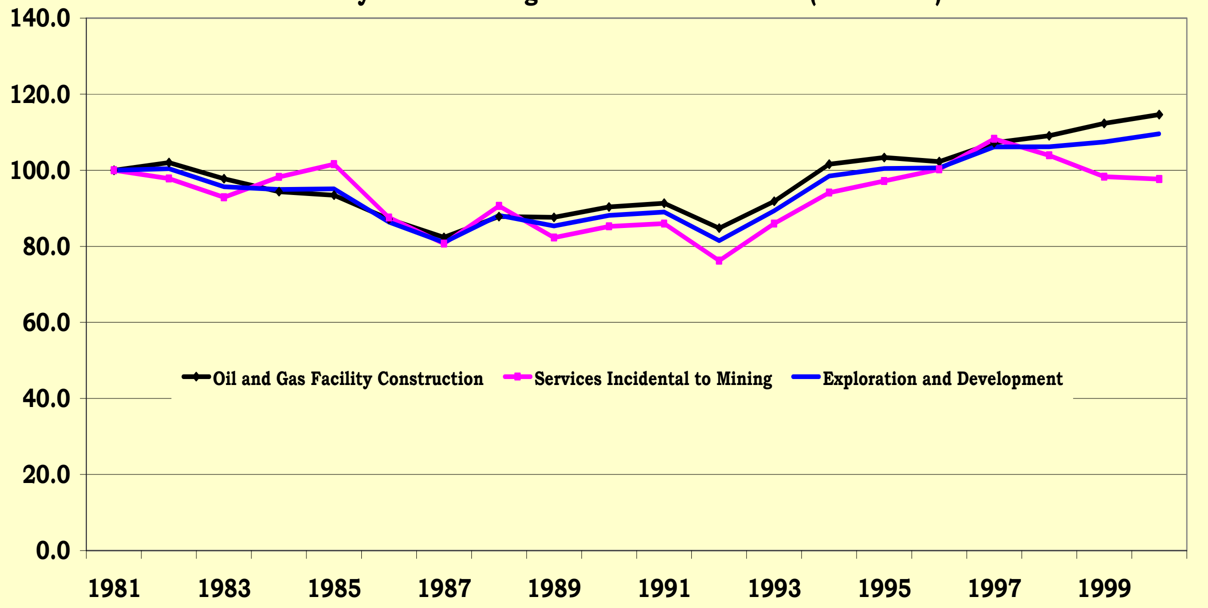
Turning to the exploration and development activity where the methodological changes consist of a new industry delineation and a revised output deflator. Under the revised production framework, the exploration and development activity now consists of two industries: oil and gas facility construction and services incidental to mining industries. The former covers establishments members of oil and gas firms engaged in the discoveries of oil and gas resources on an own-account basis. The latter, comprises establishments engaged in discoveries for natural resources outside oil and gas but also independent contractors specialized in oil and gas discoveries.

During the 1981-2000 period, exploration and development activity multifactor productivity growth grew at 0.5% on average, largely due to oil and gas facility construction which posted a 0.7% productivity gain. In contrast, services incidental to mining has seen it productivity deterioarating at -0.1% on average during the same period (Figure 3). If one is ready to accept the principle that multifactor productivity growth is a reflection of technical progress, then the lacklustre multifactor productivity growth posted by the exploration and development activity does not seem to accord with the anecdodal evidence on the high degree of innovation and rapid changes in technology that have taken place in this activity. Bohi (1998, 1) summarized as follows these changes:

> *«Over the past two decades geologists and geophysicists have developed sophisticated seismic techniques to generate mountains of data that are fed into super computers via satellites and used to build complex three-dimensional structural and stratigraphic models of the earth. Similarly, drillers now use steerable downhole motors to create wellbores that bend and turn at all angles, use sensory systems next to the drill bit to determine its location and angle and the composition of the rock layers as they are encountered. And, where not long ago the search for hydrocarbons was restricted to land areas or shallow water, now the technology has been developed to explore in water too deep to use fixed leg platforms. In this environment remote drilling systems must be used,*

production platforms must float, and pressures and temperatures are such that oil and gas flowing through subsea pipelines can turn to paraffin and crystals. Some of the changes in the technology of petroleum exploration and development rival in imagination and expense those involved in exploring outer space. They are a central part of a dramatic story of productivity change that has occurred in the industry in only ten years. »

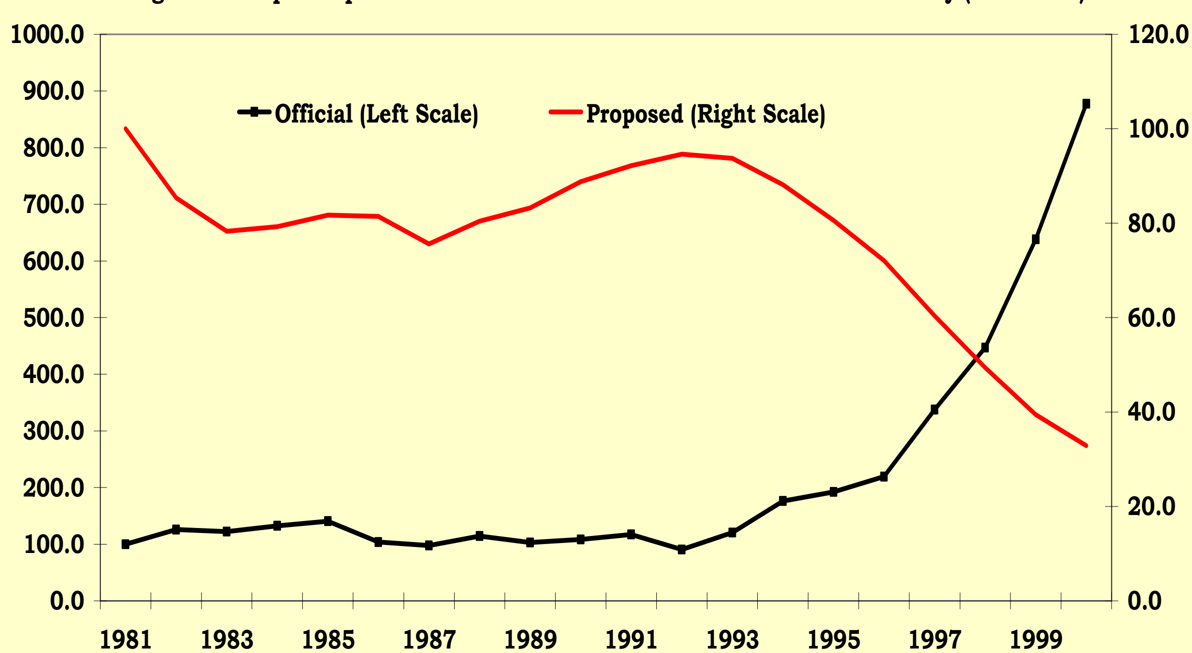
Figure 3. Multifactor Productivity Trend in the Exploration and Development Activity of the Mining Sector: Official Series (1981=100)



The examination of the data underlying multifactor productivity growth has led us to believe that mismeasurement in the real output is the prime candidate behind the anemic productivity performance of the exploration and development activity. Both industries of this activity make use of input price indexes to deflate the output, a practice that inevitably results in an absence of productivity gains. The estimates of the shadow prices of oil and gas discoveries allowed us to improve the deflator for the oil and gas exploration and development industry. This alternate price index is estimated from the hedonic cost function shown in equation (3). It, therefore, captures the technological characteristics of the this industry such as scale economies along with some of the physical characteristics of oil and gas pools. The latter suggests that quality change is accounted for in the exploration and development activity. Unfortunately, owing to a limitation of information, we have not been able to improve the output price series for services incidental to mining.

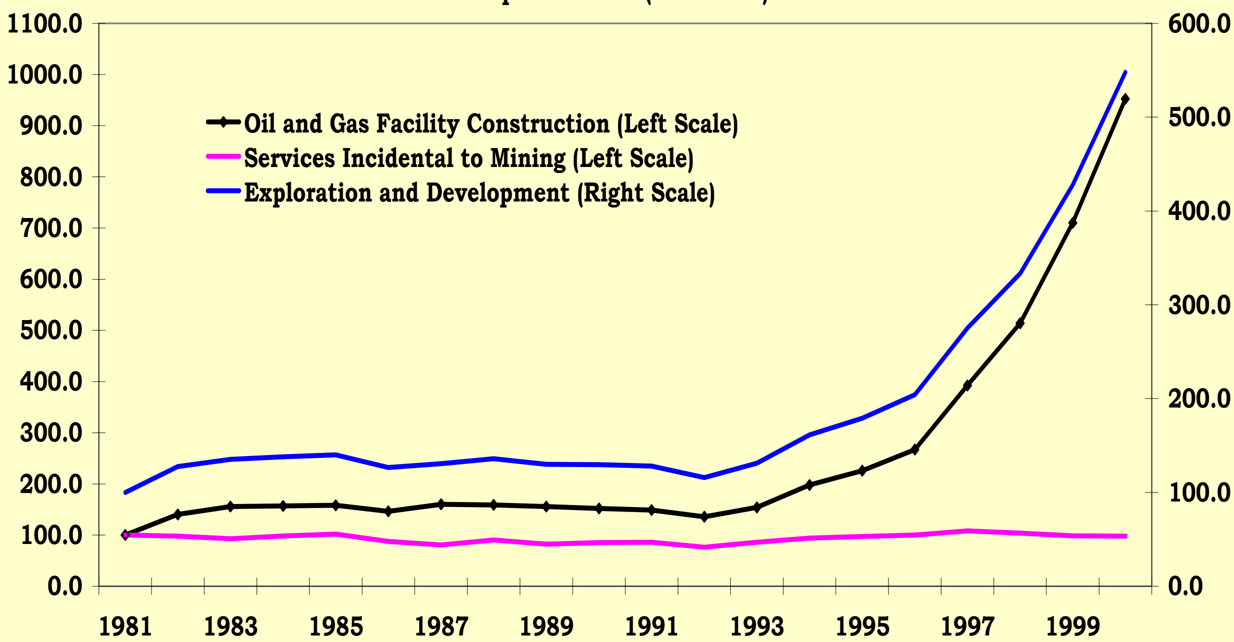
Figure 4 compares the trends displayed by the official and alternative output implicit price indexes in the oil and gas exploration and development activity. During the 1981-2000 period, the official price index increased at an average annual growth rate of 12.1%, compared to a 5.7% decline for the alternative index. The latter constitutes the shadow price for oil and gas discoveries measured as the real marginal discovery cost of oil and gas. Therefore, it captures significant economies of scale that have taken place during the expansion waves of the exploration and development activity. The first wave corresponds to the early 1980s, a period where the real marginal discovery cost declined significantly following the boom in the exploration and development activity triggered by the second oil shock in 1979. The second wave, which covers most of the 1990s, is marked by an even more precipitous decline of the real marginal cost of discoveries, following the inception of large scale projects in exploration and development for tar sands in Alberta and Hibernia in the New foundland offshore.

Figure 4. Output Implict Prices Indexes of Oil and Gas Construction Industry (1981=100)



Using this alternate output price index to construct the revised real output series drastically changes the pattern of multifactor productivity growth of the oil and gas exploration and development industry, which now experiences a 12.6% increase on average during the 1981-2000 period. Compared to the lacklustre 0.7% growth for the official estimates, this remarkable upward revision of multifactor productivity growth in the oil and gas exploration and development industry boosted the productivity performance of the overall exploration and development activity from 0.5% to 9.4% (Figure 5). While some of the cost savings are organizational in nature, the most important changes are in the application of new technologies, such as 3D seismology, horizontal drilling, and deepwater drilling used to find oil and gas (Bohi 1997). The decline in the price of oil after 1981, including especially a fifty percent cut in the price early in 1986, and the prospect that the price would not rebound in the foreseeable future, meant that firms had to find new ways of doing business. Above all, they had to reduce costs in order to improve their economic performance. The story of productivity change in the industry is very much a story of how the industry responded to the pressure to reduce costs of production.

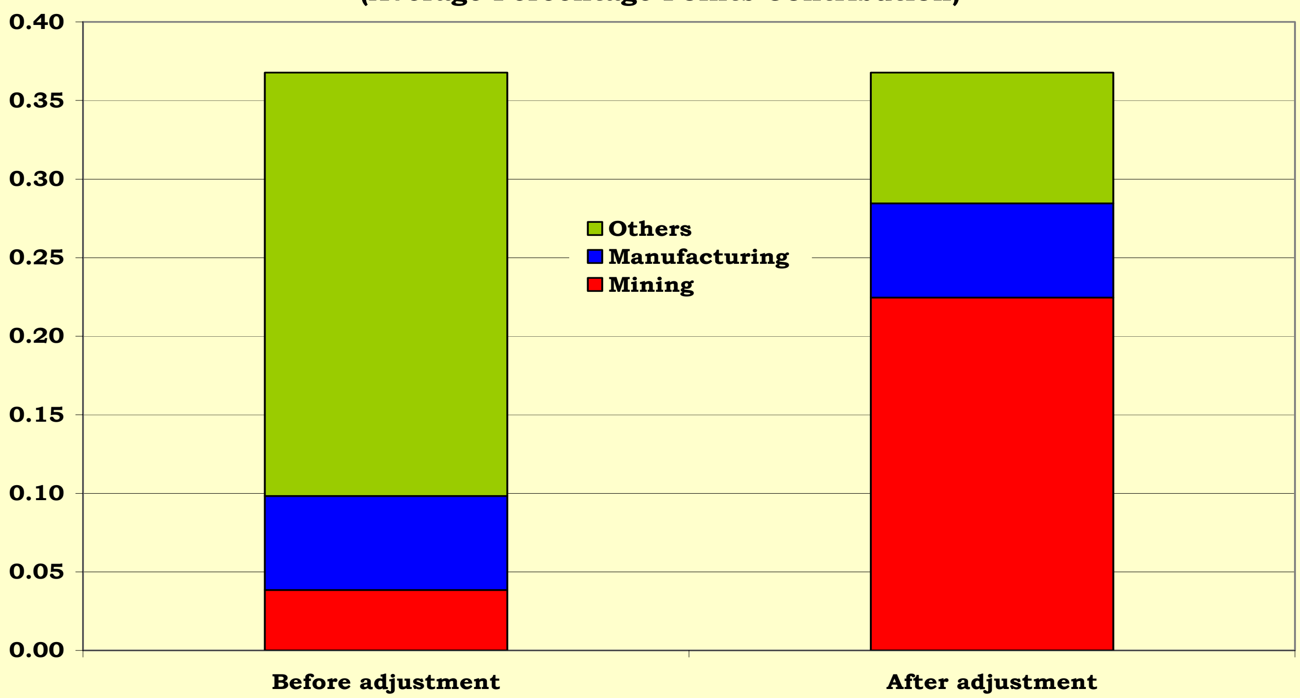
Figure 5. Trend of Multifactor Productivity in the Exploration and Development Activity: Proposed Series (1981=100)



With these revisions of multifactor productivity growth in both extraction and exploration and development activities of the mining sector, it is useful to reassess the productivity performance of the overall mining sector and to reconsider its contribution to aggregate business sector productivity growth. Over the 1981-2000 period, the overall mining sector now shows a 3.8% increase in multifactor productivity, compared to the 0.6% growth shown by the official figures. The bulk of this revision is attributable to the oil and gas exploration and development industry.

With a 4.8% average annual growth, the mining sector shows the second most rapid multifactor productivity growth of the business sector after that of computers industry which advanced at 6.5% annually. Revisions in both the size and the productivity performance have increased the contribution of the mining sector to the aggregate multifactor productivity from 10% to 61% during the 1981-2000 period (Figure 6).[6] With the alternate production framework, the mining sector now constitutes the largest contributor to the 0.37% average annual growth of the Canadian business sector multifactor productivity growth.

Figure 6. Sectoral Sources of Aggregate Multifactor Productivity Growth, 1981-2000 (Average Percentage Points Contribution)



IV. Conclusion

This paper improves in many important respects the measurement framework that has traditionally been employed for the mining sector in the CPA. It, therefore, reflects some of the efforts deployed by the CPA to improve the accuracy of the estimates of its data. These improvements, which stem from an integration of the CPA and ESA, consist of : a) a more accurate delineation of the extraction and exploration and development activities of the mining sector; b) a symmetric treatment between produced and natural capital inputs. Both of these broad

[6] Before adjustment does not refer to the official estimates as oil and gas facility construction is accounted for.

assets provide a flow of services measured in a way consistent with modern capital theory; c) a significant improvement in the measurement of real output for the exploration and development oil and gas industry.

Under this alternate measurement framework, the mining sector shows a 4.9% average annual growth of multifactor productivity during the 1981-2000 period, compared with 0.9% for the official estimates. Given that the deterioration in the quality of natural capital is not taken into account, this performance should be regarded as possibly conservative. However conservative, this upward revision not only places the mining sector as the second most productive in the business sector after the computers industry, it also reflects the benefits associated with the integration between the CPA and the ESA.

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