ACCOUNTING FOR EXHAUSTIBLE RESOURCES IN THE CANADIAN SYSTEM OF NATIONAL ACCOUNTS: FLOWS, STOCKS AND PRODUCTIVITY MEASURES

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The paper shows that the Canadian System of National Accounts includes exhaustible resources but treats them as if they were produced goods. Thus, the claim that conventional accounts ignore the contribution of exhaustible natural resources is partly true. To fully account for exhaustible resources, we present an alternative national accounting framework that incorporates natural resource flows and stocks. The framework modifies the measure of the net domestic product by a factor that differs from the Hartwick–Solow–Weitzman rule and leads to different estimates of GDP, national wealth, and productivity growth. An application to the Canadian oil and gas industry shows order-of-magnitude effects.

I. INTRODUCTION

A growing interest in the environment has raised doubts about the usefulness of current national accounting practices to answer questions of sustainable growth. An important concern is that national accounts should be modified to record exhaustible resources as a form of non-produced capital, or as an inventory of nature, in order to assess the value of changes to the natural stock brought about by economic activity. In this regard, a major proposal has been made in the literature: it is argued that since natural resources display both the flow and stock dimensions of reproducible capital, not only should their depreciation (depletion) be accounted for in the net domestic product (NDP) (Hartwick, 1990), but their mineral reserves should be part of national wealth (Hartwick, 1994). Hung (1993) shows that depreciation of natural assets is small when the matter in question is durable and can be used, once extracted, for many periods into the future. Perfect durability implies no depreciation at all. Although durable exhaustible resources should be included in national wealth, little or no economic depreciation should be deducted because of the effect of recycling. Other researchers have found negative long-term productivity growth in a number of Canadian mining industries (Cas and Rymes, 1991; Lasserre and Ouellette, 1991; Stollery, 1985). This paper shows that the productivity decline in mining industries shares the same roots as the proposed adjustment to macro aggregates in that both originate from a misconception of non-renewable resources in the conventional accounts.

In the conventional interpretation of the Canadian System of National Accounts (CSNA), natural resources are found in the output of mining industries

but not in the inputs of these industries. This occurs because the output of one of the upstream activities of mining is believed to be a produced good rather than a natural good. The capitalization of this produced good by the downstream mining activity results in a stock of reproducible assets. In contrast, we consider that the main purpose of the upstream mining activity is the search for natural resource deposits and postulate that the output of this activity consists of the discovery of natural resource pools and information about the resource. Discoveries accumulate in a stock of reserves-inventories, a non-produced, or natural, capital asset, which is subsequently drawn down by the downstream activity to produce mining gross output.

Recognition of the natural resource input lead us to a reconsideration of all exhaustible natural resource flows as well as stocks. This is achieved by treating natural resources in a way that is consistent with production theory and natural resource valuation principles. We do this in an alternative integrated accounting framework. The new accounting framework leads to adjustments in gross and net domestic product that are consistent with the Hartwick–Solow–Weitzman (HSW) rule. However, the adjustment factor suggested by the proposed accounts is not identical to the HSW rule. The difference occurs because part of the total value of natural resources is taken into account in the conventional account's measures of GDP, NDP, and national wealth.

The integrated accounts proposed here (i) identify the natural resource inputs to the economic system, (ii) identify resource flows within extractive industries, (iii) define an industry-controlled reserve-inventory of natural resources, (iv) link extractive industry output with natural resource extraction, thus allowing a new definition of gross domestic product and sustainable income consistent with natural resource depletion, and (v) include the value of discovered natural resources in the value of national wealth and net worth. The application of this framework to the Canadian oil and gas industry demonstrates that most of the impact is on the constant price values of stocks, flows, gross and net domestic product. The framework also yields significantly different productivity growth rates than the ones based on the existing accounts.

The outline of the paper is as follows: Section II describes the current treatment of extractive activity in the CSNA, Section III presents the integrated accounting framework, Section IV elaborates on some of its implications, Section V shows the empirical application, and Section VI concludes.

II. THE CURRENT TREATMENT OF EXHAUSTIBLE RESOURCES IN THE CSNA

The CSNA shows natural resources first entering the chain of production and distribution as the output of extractive industries. Natural resources are subsequently purchased by intermediate- and final-demand users for further transformation into other products or for use as a form of energy. Even though extractive industries engage in the extraction of resources as part of their total activity, the accounts do not explicitly show the discovery of resource pools, the reserve-inventory controlled by extractive industries, or the draw down (extraction) from reserves-inventories in such industries. Natural resources are believed to be excluded from the inputs of extractive industries in the conventional

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accounts, thus suggesting that the accounts overstate net national product (NNP) (Hartwick, 1990) as no economic depreciation of the natural asset is explicitly deducted from conventional GDP.[1] Solow (1986) argued that national income should be reduced by the value of depletion to reflect the loss of the natural stock not available to future generations. Hartwick (1994) suggested that national wealth is underestimated since neither the stock of natural resources nor the stock of reserves-inventories is part of the national balance sheets.

The need to incorporate natural resources into the accounts is in part a response to the question of sustainable development and is being addressed by amendments to the existing national accounts. In one important case, natural resource accounting is being developed in satellite accounts while the core accounts are maintained in their present state. Satellite accounts are linked to the core accounts by showing natural resources as the satellite's "exports" to the conventional accounts, where natural resources are shown as "imports" (see Bartelmus *et al.*, 1991; Carson, 1994). This approach, however, does not fully integrate natural resources into the existing accounts, reflecting the prevailing view that the conventional accounts contain no transactions related to natural resources. This, we will argue, is not the case.

In this paper the focus is on the complete accounting of non-renewable natural resources at the firm and industry levels. In our framework, firms acquire resource rights, discover resource deposits, hold and use reserves-inventories of natural assets and draw down natural stocks in order to produce output. Thus, a flow of natural resources enters the economic system as inputs at the level of the exploring and extractive firms, a phenomenon not recognized by the conventional accounts. To gain an understanding of what is involved, we first describe the structure of the existing accounts, with a focus on the treatment of flows and stocks in extractive industries, and then present the alternative accounting treatment, which introduces changes to the structure of the accounts. Some of the macroeconomic implications of this framework are also discussed.

In the CSNA, the flows of goods and services among industries and between industries and consumers are recorded in the input–output accounts (I–O–A). The accumulation of capital goods is recorded in the capital stock and national balance sheet accounts. Given that exhaustible resource exploitation takes place in the mining industries, we concentrate on the treatment of mining industries in these accounts.

1. *Input–Output Accounts*

The I–O–A present a complete description of industry flows in three flow transaction matrices: the Make, Use, and Final Demand matrices. These matrices show the production of commodities by industries, the use of commodities by industries, and the disposition of commodities into consumption, investment, net exports, and changes in inventory. The accounts consider that mining industries engage in two types of economic activities: the extraction and processing of

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[1]See Lozada (1995) on the current U.S. practice with regard to depletion measurement.

resources, and the construction of facilities for own use (own-account construction). The mining industry shown in the Make and Use matrices refers to the extractive and processing activity of the industry. Own-account mining construction activity is shown in these matrices as part of the construction industry.

The own-account (upstream) activity uses labour and intermediate inputs to produce an output consisting, conceptually, of "improvements to the land." The extractive and processing activity of the mining industry capitalizes its own "land improvements" output as well as other investments it makes. This is shown in the final demand matrix. Total investment by mining industries is disaggregated into two main components, each representing similar types of assets: machinery and equipment, and construction. Construction investment is further disaggregated into building construction and engineering construction. The capitalization of "land improvements" is reflected in the accounts by showing industries purchasing their own-account construction output as part of total industry investment. This output is capitalized by the extractive and processing activity as part of its engineering construction component of capital stock.[2] The other two components of capital stock are purchased from other industries. The extractive and processing (downstream) activity, in addition to using capital services from these stocks, uses labour, intermediate inputs, and resource taxes and royalties to produce extractive activity gross output.

Let us formalize the treatment of mining activity in the accounts. Bearing in mind that total revenue equals total cost in all productive activities, the value of own-account mining construction output is

$$(1) \qquad\qquad V^O = w_L L^O + w_M M^O,$$

where superscript O designates own-account activity, V^O is nominal gross output, and w denotes the input price of labour (L) and materials (M) used.[3]

The value of mining extractive and processing activity output is

$$(2) \qquad\qquad V^P = w_L L^P + w_M M^P + \sum_i u_i K_i + R_y + T_r,$$

where $i = ME$ (machinery and equipment), BC (building construction) and EC (engineering construction); superscript P denotes the extraction and processing activity, V^P is nominal gross output, u_i is user cost of capital;[4] and R_y and T_r represent government royalties on natural resources and resource taxes (in particular, exploration rights and bonuses).[5] The value of mining capital stocks is calculated by the perpetual inventory method,

$$(3) \qquad\qquad P_{i,t} K_{i,t} = V_{i,t} + (1 - \delta_{i,t}) P_{i,t-1} K_{i,t-1},$$

where $K_{i,t}$, $V_{i,t}$, $\delta_{i,t}$ and $P_{i,t}$ designate, respectively, capital stock, investment, the depreciation rate, and the price of stock component i.

[2]The industry may also purchase engineering construction from other resources such as services incidental to mining industries, but these are ignored for simplicity of presentation.

[3]There is no capital input in own-account construction activity. All mining capital is allocated to the extractive activity.

[4]The user cost of capital is defined as interest cost plus depreciation minus capital appreciation.

[5]The value of commodity indirect taxes other than natural resources taxes and subsidies are not shown separately. One may assume they are distributed to the commodities to which they apply.

This framework highlights the main features of the accounts that provide measures of GDP, NDP, and productivity. We now turn to the accounts that measure wealth.

2. National Balance Sheet Accounts

The Canadian National Balance Sheet Accounts (CNBSA) record three main types of assets and liabilities that are, in principle, measurable. They include tangible assets such as produced capital stock (e.g. housing, industrial plant, machinery, and transportation infrastructure), land in productive use (i.e. agricultural, commercial and residential land), and financial assets and liabilities (e.g. domestic savings and investments, Canadian investment abroad, and foreign investment in Canada). National wealth (W) and net worth (N) are defined as follows,

$$(4) \qquad W = NFA = RS + NRS + ME + CD + I + L$$

and

$$(5) \qquad N = W + FA - LIAB$$

where NFA, RS, NRS, ME, CD, I, L, FA, and $LIAB$ represent, respectively, non-financial assets, residential structures, non-residential structures, machinery and equipment, consumer durables, inventories, land, financial assets, and liabilities.

Most financial assets and liabilities are valued at their book value. The value of non-financial assets is based on the perpetual inventory method, and it is net of depreciation (linear depreciation pattern). The value of land in productive use, that is, agricultural, commercial, and residential land, is included. Exhaustible natural resources are believed to be excluded from the CNBSA, but as will be shown below, part of the value of these non-renewable resources is included in the value of residential structures.

III. INTEGRATING EXHAUSTIBLE NATURAL RESOURCES TO THE CNSA

1. Re-Examining the Conventional View

Our point of departure in the integration of natural resources is a re-examination of the conventional notions of own-account construction activity as a type of construction activity and of land improvements as the output of this activity. "Improvements to the land" as a concept of output corresponds to the well-established national accounting notion that natural resources cannot be created, only transformed. In this conceptualization, the output of own-account construction activity consists of information about the resource, such as its size and grade, the physical access to the resource, such as roads, exploratory drilling, and tunnels, but not the resource itself.

Since land improvement is a produced good in the existing accounts, so too is the resulting capital asset. No natural resources are included in the input set of the own-account construction activity nor in the input set of the extractive activity of mining firms. The origins of the natural resource found in the output of mining

firms is unaccounted for, and it is not possible to provide an explanation of the physical origins of the natural resource as it enters the economic system.

The accounts are further limited by the estimation of the real value of own-account output. Real own-account output is calculated by deflation, using a composite price index that includes a component of the input price index. In the case of the oil and gas industry, most of the own-account output is deflated by a price index that is dominated by the drilling price index. Since drilling is also a dominant input, the use of an almost identical deflator for inputs and output introduces a downward bias to the measure of productivity in the activity. To reduce the productivity bias, the output price should be as independent as possible from the input price, or, preferably, real own-account output should be measured directly, without resorting to deflation, as proposed in the alternative accounts presented here.

2. Redefining Own-Account Output

The above considerations cast doubts about the usefulness of the notion of own-account mining activity as a construction activity and of land improvements as the output of this activity. As an alternative, we postulate that the principal intent of own-account mining construction activity is the search for resource deposits, and we therefore rename the activity the exploration and development activity (E&D). E&D is a multi-product activity whose outputs are the discovery of resource pools and information about these resource pools. (See Quyen, 1991 for a similar view.) The discovery component of E&D output implies that the firm establishes private property rights to the natural resource pools it has found, in particular, the right of the firm to the subsequent extraction of the mineral found and the appropriation of its market value. The information component of E&D output is used in the evaluation of future exploration prospects. The firm uses the information to reduce the degree of uncertainty that characterizes the exploration process. Uncertainty arises because the exploring firm must typically undertake a sunk cost before the true state of nature is revealed. Information conveys two types of externalities to the exploring firm: (i) it changes the likelihood of finding additional deposits and (ii) it creates a common access problem of exploration land, or "gold-rush" phenomenon, that can lead to excess valuation of adjacent lands. Both these arguments have some empirical support (Cairns, 1990).

3. The New Accounting Framework

We propose a framework in which natural resources are inputs to the economic system at the level of the exploring and extracting firms and where there are natural resource flows and stocks. The framework identifies discoveries of natural resources, the transfer of natural resource ownership from its original owners (citizens in most cases) to the exploring firm, and from these firms to other downstream users. The framework also identifies the firm's stock of reserves-inventories and the reserve-inventory drawn down corresponding to conventionally defined mining gross output. Integration can be achieved by modelling mining industries as having two vertically integrated activities: the E&D activity and the

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extractive activity. The inputs to the E&D activity consist of the labour and intermediate inputs employed in the own-account construction activity,[6] which are expanded to include the value of natural resource rights to the industry. One of the output flows of the E&D activity—discoveries—gives rise to the stock of reserves-inventories in the extractive activity of the mining industry, an activity that is similar to the production activity in the conventional accounts. The other output flow of the E&D activity—information—remains in the E&D activity. The extractive activity also holds a stock of produced capital assets that now includes only the building construction and machinery and equipment components of capital stock. The engineering construction capital stock is replaced by the reserve-inventory stock. (The rationale for this is discussed below.) In order to generate output, the extractive activity of the industry uses capital services from the produced stocks, other service inputs (labour and other intermediate inputs), and the services of the stock of reserves-inventories. It acquires extraction rights by paying royalties.

The new framework has the following features: (i) discoveries are explicit, (ii) the payment of resource rights (T_r) previously treated as an extractive activity cost is now considered an E&D activity cost, (iii) the stock of reserve-inventory is controlled by the firm, and (iv) royalties, which were treated as an intermediate input to the mining industry in the conventional accounts, are now treated as payments for the natural resource.[7]

It is worth emphasizing that the existing accounts correctly measure the current value of all the inputs and outputs of the mining industry. Although the nominal value of output in each of the two mining activities is different for conventional and integrated accounts, because of the transfer of resource taxes from the extractive and processing activity to the E&D activity, the mining industry's nominal value of output as a whole remains unchanged, that is

$$(6) \qquad\qquad V^O + V^P = V^{ED} + V^E,$$

where V^{ED} and V^E stand, respectively, for E&D and extraction activity outputs in the new accounts. The value of E&D output is[8]

$$(7) \qquad\qquad V^{ED} (\equiv z^+ R^+ + Y) = w_L L^O + w_M M^O + T_r,$$

where R^+ is the volume of mineral discoveries, z^+ is its price, Y is the information value of discoveries, w is the price of labour and intermediate inputs, and T_r is the cost of resource rights.

The value of extractive output in the new accounts includes the remaining cost to the industry, which now includes the cost of holding and drawing down the stock of reserves-inventories as well as the value of service input of produced capital assets. The value of service input of a produced capital asset has two main components: the value of the opportunity cost of holding the asset, $(r - \pi) \cdot P \cdot K$, and the value of depreciation, $\delta \cdot P \cdot K$, where r is nominal rate of interest, π the

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[6]Capital services and geological and geophysical expenditures should also be included in E&D inputs.

[7]It might be argued that resource taxes are also payment for the natural resource.

[8]Like the own-account construction activity, the E&D activity does not have capital inputs even though it should.

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rate of inflation of the asset price, δ the depreciation rate, P the price of the asset, and K the volume of capital stock. Since reserves have features similar to produced capital stock (both have the flow and stock dimensions), the value of service input from the stock of reserves-inventories also has two components: $\phi \cdot R$, the opportunity cost of holding the resource-inventory asset, and $z^- R^-$, the value of the resource inventory drawn down (extraction). The value of extraction output is therefore given by

$$(8) \qquad V^E = w_L L^P + w_M M^P + \sum_j u_j K_j + \phi R + z^- R^- + R_y,$$

where $j = ME$, BC; R is the volume of reserves-inventories and ϕ its rental price; R^- is the volume of extraction and z^- its price; R_y is the value of royalties; and u is the user cost of produced capital.[9]

There is an important relationship between the accounts. Substituting equations (1), (3), (7), and (8) into (6) gives

$$(9) \qquad u_{EC} K_{EC} \equiv (r - \pi + \delta)_{EC} P_{EC} K_{EC} = \phi R + z^- R^-.$$

Equation (9) shows the equality between the nominal service input value of the engineering construction component of capital stock in the existing accounts and the value of the service input of the reserve-inventory in the alternative accounts. In other words, the conventional accounts include part of the value of the natural resource input. In addition, given the similarities between the value of E&D output and that of own-account output, the value of reserves-inventories also appears in the value of the engineering construction component of capital stock in the conventional accounts. Therefore, conventional account estimates of produced capital and wealth include part of the value of the stock of reserves-inventories, a non-produced asset.

Even though the structure of the new accounts is similar to that of the existing accounts, some major differences are worth mentioning. The integrated accounts explain resource flows within the industry. Beginning with the acquisition of mineral rights as input of the E&D activity and discoveries as its output, discoveries are invested by the extractive activity in its inventory of reserves. In turn, the reserve-inventory drawn down by the extractive activity gives rise to the natural resource output of the industry, completing the integration of natural resource flows at the level of the extractive industry. In relation to the conventional accounts, own-account construction output is replaced by discoveries and information, the engineering construction component of capital stock is replaced by an inventory of reserves, and the service input of the engineering construction stock is replaced by the services of the reserve-inventory. By not taking account of the natural resource input, the existing accounts treat the engineering construction component of capital stock as a stock of produced capital assets. This stock has a different opportunity cost and depreciation pattern relative to the stock of reserves-inventories. These differences are critical to the measurement of macro-aggregated discussed in the next sections.

[9]The effect of capital-related taxes and subsidies on the user cost of capital is not shown. The inclusion of these taxes and subsidies does not alter the conceptual conclusion of the paper.

IV. Implications of Integration

1. *Flow and Stock Accounts*

In the neoclassical interpretation of production activity there are two primary production factors: the services of labour, in the sense of human effort, and the services of capital, in the sense of the use of capital assets. Both these inputs represent some form of human sacrifice. The supply of labour implies forgone leisure, and the supply of capital necessitates the postponement of present consumption for future consumption. Neoclassical production theory does not assign a role to natural resources, which gives rise to the belief that such resources are not an important element in economic activity or, alternatively, that natural resources are a free gift of nature. The typical national accounts reflect this view by treating resource taxes and royalties as taxes that are paid to governments in return for an unspecified government service.

It is now recognized that the consumption of non-renewable natural resources implies a sacrifice, in a sense, analogous to that of the primary inputs of neoclassical theory and that this may occur irrespective of whether the resource can be considered to belong to the present or to the present and future generations. Solow (1986) argues that if exhaustible natural resources belong to the present generation and social utility increases with wealth, the consumption of the resource stock implies a sacrifice in the sense that it reduces wealth. If the stock of exhaustible resources is thought to belong to the present and future generations, and if each generation has equal weight in the utility function, the use of the resource by the present generation may also imply a loss of intergenerational utility and, therefore, a current sacrifice. It is as a loss of endowment of the natural resource stock that exhaustible resource consumption could be viewed as a category of primary inputs. We adopt the notion that the consumption of exhaustible resources is a primary input and evaluate the implications on the measures of production, income, and wealth within the context of the integrated accounting framework.

A. Industry GDP and NDP

In the conventional accounts, mining industry GDP at factor cost is the sum of payments for the services of labour and produced capital assets, that is

$$(10) \qquad GDP^C = w_L L^P + \sum_i u_i K_i,$$

where C refers to conventional accounts $i = ME$, BC, EC and P refers to the conventional account's extractive and processing activity of the industry.

In the integrated accounts (referred to by superscript I), extractive activity GDP includes the services of labour and produced capital, the opportunity cost of holding the reserve-inventory stock, and the value of service input of the natural resource inventory. The value of the opportunity cost of holding reserves-inventories is analogous to that of produced assets, which is given by the difference between the interest cost of inventory and the rate of increase in inventory value due to capital appreciation. If the extractive firm operates at the optimal extraction rate, i.e. at the output rate that maximizes the present value of the firm, the price

of a unit of reserves grows at the same rate as the nominal rate of interest. In this case, and if firms finance the acquisition of reserves by borrowing at the nominal interest rate, the growth in the value of reserves at any point in time will fully compensate for the interest cost. Holding reserves carries no cost to the firm in this instance, but factors such as holding asset taxes and subsidies may convey a benefit or cost to the firm for holding this asset.

The value of the natural resource service to be included in GDP in a given period is the value of the natural resource income generated by the activity during the period. Under optimal circumstances, the value of natural resource income corresponds to payments made by the extractive industry to natural resource owners. In the CSNA, such income is composed mainly of natural resource royalties. In the integrated accounting framework, the primary income generated by the exploitation of a non-renewable natural resource is the payment by the extractive industry to the original owners of the resource, which we substitute by the value of royalties. Equality between private and public valuation of the natural asset is assumed.

Extractive activity GDP in the integrated accounts is given by

$$(11) \qquad GDP^I = w_L L^P + \sum_j u_j K_j + \phi R + R_y$$

where $j = ME, BC$. Taking (9) into consideration, the difference between GDP values in both accounts is

$$(12) \qquad GDP^I - GDP^C = (\phi R + R_y) + [(r - \pi)P_{EC}K_{EC} + \delta_{EC}P_{EC}K_{EC}].$$

GDP differs between the accounts mainly by the difference between royalties and resource extraction. Two features are important in this comparison. The integrated accounts include the value of royalties in extractive activity GDP while the conventional accounts treat royalties as an intermediate input at the extractive and processing activity level. However, the I–O–A include royalties as a primary input at the economy level, reducing the difference in (12) to the value of extraction. However, the reason royalties enter GDP differs: the CSNA treats royalties as a return on reproducible capital while the integrated accounts treat royalties as a payment for a natural resource asset. Further, the allocation of the value of GDP among primary inputs is different; in the integrated accounts, the contribution of natural resources takes a larger proportion of value added because of the exclusion of engineering construction stock.

The concept and measure of NDP in the conventional accounts also differs from that in the integrated accounts. The conventional accounts adopts the Hicksian definition of net domestic product:[10] the portion of current production that can be consumed in order to maintain the stock of wealth at a constant level. Therefore, the depreciation of tangible assets is deducted from GDP, i.e.

$$(13) \qquad NDP^C = w_L L^P + \sum_i (r - \pi)_i P_i K_i,$$

where $i = ME, BC, EC$.

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[10]In the CSNA, NDP is measured on the income side of the accounts and called net domestic income.

This measure of net income implies that future generations will have access to the same productive capacity as the present generation, since the value of wealth in the accounts is believed to refer to productive assets, including productive land. Thus, it is thought that this intertemporal transfer of productive capacity would at least equalize consumption across generations, even in the absence of technological progress.

In the integrated accounts, the value to be deducted from GDP in order to arrive at NDP is the depreciation of produced capital and the depreciation of the natural asset (value of the natural resource consumed, or depleted). The value of the natural resource consumed in a given period may differ from the value of natural resource income, depending on the durability of the extracted resource. Durable resources such as gold experience very little final consumption because of extensive recycling, while other resource types, such as hydrocarbons, are mostly consumed. Thus, little is to be deducted from GDP in the case of durable natural resources (Hung, 1993). In the integrated accounts, Hicksian net income or net domestic product is obtained by deducting from GDP a fraction of the natural resource primary input value included in GDP, where the fraction corresponds to the degree of final resource consumption,

(14) $$NDP^I = w_L L^P + \sum_j (r - \pi)_j P_j K_j + \phi R + (1 - \alpha) R_y,$$

where $j = ME, BC$. The fraction α indicates the degree of natural resource durability—equal to 1 if the resource is non-durable and 0 if durable. An implication is that durable resources generate a royalty income that can be consumed without reducing net worth.

The difference between the net domestic product of both accounts is

(15) $$NDP^I - NDP^C = \phi R - (r - \pi)_{EC} P_{EC} K_{EC} + (1 - \alpha) R_y$$

$$= \delta_{EC} P_{EC} K_{EC} - z^- R^- + (1 - \alpha) R_y.$$

In the conventional accounts, the adjustment to industry GDP necessary to obtain NDP is the depreciation of the physical stock of capital. In the integrated accounts, the adjustment consists mainly of deducting the value of depreciation of a smaller physical stock (engineering construction excluded) from GDP and the value of natural resource use, if any.

When natural resources are an input of the economic system, the transfer of productive capacity to future generations may not necessarily provide the same level of output if there are limits to the substitution of capital for natural resources. Using an approach similar to Weitzman (1976), Hartwick (1977) showed that in a society fully using its capital and labour, with substitution possibilities, constant returns, and no technological progress, a constant stream of consumption over time will be obtained if the value of resource rents is completely reinvested at every point in time. Solow (1986) interpreted Hartwick's results as the intergenerational transfer of an expanded stock of wealth, which includes natural resources as well as produced assets. A straightforward interpretation of the HSW concept of sustainable income requires deducting the value of depletion of the natural resource from conventionally measured GDP. In contrast, the adjustment to GDP necessary to arrive at NDP in the integrated framework differs from the full

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deduction of the economic depreciation of the natural resource capital suggested by the HSW rule. In our context, GDP is instead reduced mainly by the difference between the depreciation of the engineering construction component of capital stock and the depletion of the natural resource.

The last step to complete the macro implications is to show how the integrated accounting framework affects national wealth and net worth.

B. National Wealth and Net Worth

The non-residential structures component of tangible assets includes the current and constant values of the engineering construction component of capital stock resulting mainly from the capitalization of own-account output. Given the numerical similarity between the value of own-account construction output and E&D output, the capitalization of own-account construction output in the conventional accounts has an impact on the balance sheets similar to the capitalization of E&D output in the integrated accounts, with the exception of the value of information, which is not capitalized as a tangible asset. Thus, contrary to what is commonly asserted, the CNBSA already includes part of the value of the exhaustible resource stock in the estimates of national wealth.

The valuation of the reserve stock should be consistent with exhaustible resources valuation principles, i.e. it should rely on the concept of Hotelling rent. On theoretical grounds, it is unlikely that the perpetual inventory of engineering construction stock would have the same value as the value of reserves stock measured on the basis of scarcity rent. First, both assets are different in nature: one is reproducible while the other is exhaustible. Assuming that both assets are evaluated by the present value of the flow of future returns, both would have different values because of different planning periods, endogenous for a non-renewable natural stock and exogenous (and perpetual) for reproducible capital. Second, the underlying assumption of the perpetual inventory method is that the asset, although having a finite life, can be constantly replaced. In this method, the flow of capital services is a quantity index of capital inputs from durable goods of different vintages. Under perfect substitutability among the services of durable goods of different vintages, the flow of capital services is a weighted sum of past investments. The weights correspond to the relative efficiencies of the different vintages of capital.

This simple version of the perpetual inventory method cannot be applied to exhaustible resources. Although depreciation is the way efficiency is measured for a produced capital stock, natural capital stock depletes, and it may be subject to a degradation of quality as depletion takes place, Except under very special circumstances, it is unlikely that depreciation will equal depletion. Finally, even though the valuation of both assets rests on the same spirit of valuation—the replacement cost approach—the fact remains that the value of produced capital is based on a total cost approach whereas natural capital stock valuation is based on a marginal cost approach, as a substitute for Hotelling rent.

In the CNBSA, the engineering construction component of capital stock is included in non-residential structures. The proposed treatment, which mirrors the treatment made in the flow account, consists of creating a class for non-renewable assets (*NRA*) as part of total assets and netting out the value of the engineering

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construction component of capital stock from non-residential structures. The resulting value of wealth in the integrated accounts is based on produced assets, land, and non-renewable assets

$$W^I = W^C - P_{EC}K_{EC} + NRA$$

(16)
$$= RS + (NRS - P_{EC}K_{EC}) + ME + CD + I + L + NRA$$

$$= PA + L + NRA,$$

where I and C refer to integrated and conventional accounts. PA and NRA designate, respectively, produced and non-renewable assets. Other variables were defined above.

The value of net worth in the integrated accounts is

(17)
$$N^I = NFA - P_{EC}K_{EC} + FA + NRA - LIAB.$$

2. *Productivity in the Integrated Accounts*

In a number of Canadian mining industries, conventionally measured multi-factor productivity (MFP) shows a long-term decline. Productivity increased in the 1960s but declined markedly in the 1970s, followed by a partial recovery (Cas and Rymes, 1991; Lasserre and Ouellette, 1988; 1991). Statistics Canada's experimental MFP estimates using the production function of the conventional accounts and CSNA data show that the level of mining gross-output multifactor productivity in 1989 was below the level of 1961.[11]

The MFP measure in the integrated framework differs from that in the conventional accounts. By including exhaustible resource inputs, the new measure of productivity includes the services of the stock of reserves as part of the total inputs and excludes the services of the engineering construction component of capital stock. Even though the nominal values of these services coincide, as indicated by equation (9), there is a substantial difference in the quantity of service flows derived from the stocks. In particular, conventional accounts productivity assumes that the service input of the engineering construction capital stock is proportional to the volume of the stock, whereas in the integrated accounts the service input of the reserve stock is generally not proportional to the volume of reserves. The volume of reserve-inventory service input has two components: the volume of extraction and the volume of services that corresponds to the opportunity cost of holding reserves. The volume of extraction can be measured in physical units, whereas the volume of the opportunity cost of holding reserves may be assumed to be proportional to the volume of reserves or may be derived residually.

Some researchers include the total volume of produced capital stocks in the accounts as well as the stock of reserves in the inputs of the mining industry, such that the production function is written as $Q = f(K_{BC}, K_{ME}, K_{EC}, R, L, M, t)$ (see for instance Halvorsen and Smith, 1984; 1991; Lasserre and Ouellette, 1991). This specification is based on the generally held view that natural resource stocks are excluded from the conventional measures. However, the specification results in

[11]Conventional accounts mining industry productivity refers to the extractive activity of the industry.

double counting of the stocks, given that the engineering construction component of physical capital includes part of the natural resource stock. Not surprisingly, this specification yields negative productivity growth rates (Halvorsen and Smith, 1986). The integrated accounts eliminate double counting by specifying $Q = f(K_{BC}, K_{ME}, R, R^-, L, M, R_y, t)$, which is the primal production function corresponding to equation (8).

V. Application to the Canadian Oil and Gas Industry

This section compares the nominal and real value of key variables in the conventional and integrated accounts.[12] Reference is made to the extractive activity of the Canadian oil and gas industry, chosen not only for its dominance in total mining (oil and gas account for 68 percent of mining gross capital formation) but also because it accounts for 96 percent of the total value of royalties. We used full marginal discovery cost to measure the price of the resource (see Lasserre, 1985). This concept is appealing because it allows the shadow price of oil and gas to be measured without imposing restrictive hypotheses on the firm's technology (a hypothesis of constant return in this case), and it permits the natural resource stock and inventory drawn down to be measured in current and constant prices.

1. Flow and Stock Estimates

Table 1 allows us to compare own-account output with discoveries, engineering construction capital stock with reserve-inventory stock and engineering construction depreciation with depletion (royalties). The value of own-account output increased from 1962 to 1985, after which it declined. The value of discoveries generally followed the same trend. However, the difference between the two grew over time, especially after the first oil shock and even more so after the second. This difference has an economic interpretation: it represents the value of information output associated with the E&D activity [see (7)].

Reserves-inventories stock is larger than engineering construction capital stock, indicating that the existing acounts underestimate national wealth and net worth. The depreciation of mineral reserves (royalties) and the depreciation of engineering construction stock were somewhat similar in value at the beginning of the series but then diverged after 1973. Two distinct periods emerged during the post 1973 era. Between 1974 and 1984, the depreciation of natural assets averaged $1 billion per year more than the depreciation of engineering capital. For the subsequent period, the value of engineering stock depreciation exceeded royalties by $2.3 billion per year on average. For the 1962–89 period, the existing accounts overestimate the value of depreciation of the natural assets by only $370 million.

Table 2 contains the variables in Table 1 in constant prices. It shows that differences between the integrated and existing accounts are now much larger. The real output of mineral discoveries is volatile because of fluctuations in the physical volume of discoveries that occurred over the period. The value of reserve-inventory and engineering construction capital stocks in constant prices exhibited

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[12]The data set is available on request from the authors.

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TABLE 1

FLOWS AND STOCKS IN THE CONVENTIONAL AND INTEGRATED ACCOUNTS:
CANADIAN OIL AND GAS INDUSTRY

(Millions of Canadian Dollars)

Year	Own-Account Output	Discoveries	Engineering Construction Capital Stock	Reserves Stock	Engineering Construction Depreciation	Mineral Reserves Depreciation
1962	201.6	94.5	955.9	2,824.1	152.6	94.2
1963	235.0	111.7	1,047.1	3,743.0	168.3	99.3
1964	264.7	124.0	1,142.4	4,410.5	185.1	107.5
1965	337.7	186.5	1,313.7	3,207.9	211.4	142.8
1966	344.0	151.2	1,480.0	6,146.7	246.1	139.9
1967	327.8	189.3	1,605.3	5,977.8	275.9	175.7
1968	340.1	175.5	1,667.9	9,330.7	291.3	190.7
1969	375.3	228.2	1,814.6	10,005.7	320.8	209.6
1970	479.0	217.3	2,025.7	16,627.1	355.7	224.7
1971	486.1	245.6	2,392.0	15,145.6	431.5	261.5
1972	631.8	231.0	2,676.7	22,479.3	482.7	303.8
1973	733.5	292.1	3,048.8	11,870.1	555.6	412.8
1974	916.5	513.0	3,840.1	27,374.2	708.1	1,247.2
1975	1,181.6	698.2	4,836.4	57,489.9	896.4	1,627.3
1976	1,401.3	628.0	5,575.2	31,251.7	1,035.2	1,968.3
1977	1,794.3	1,087.8	6,606.6	31,337.2	1,215.7	2,300.5
1978	2,397.1	1,419.6	8,035.5	31,429.6	1,476.4	3,125.4
1979	3,593.6	1,595.7	10,508.4	24,477.5	1,895.0	3,735.5
1980	5,035.5	1,576.7	14,153.3	50,242.2	2,537.0	4,457.2
1981	5,151.9	1,535.4	17,600.3	79,954.0	3,290.4	4,543.7
1982	5,439.5	2,004.1	20,939.3	130,987.1	4,024.8	4,893.3
1983	5,481.8	4,212.3	22,518.0	245,559.7	4,413.2	5,466.6
1984	6,354.5	2,577.3	24,846.2	55,422.6	4,878.3	5,695.8
1985	7,298.7	1,435.6	27,700.4	79,725.3	5,531.5	5,372.1
1986	4,991.6	1,830.2	26,904.4	113,306.8	5,732.4	3,048.9
1987	3,927.0	1,677.3	26,033.1	100,481.8	5,793.7	2,576.9
1988	4,872.0	1,282.5	25,904.3	78,154.5	5,779.1	2,795.6
1989	4,209.1	1,237.2	25,034.9	93,291.3	5,757.7	3,058.7

two substantially dissimilar trends and levels. After an upward trend that peaked in 1969, reserve stocks began a steady decline. Engineering construction capital stocks grew steadily until 1978, then accelerated until 1985, and declined thereafter. In addition to differences in trends, there is a substantial difference in level, implying that the national accounts underestimated real national wealth by $116 billion per year on average between 1962 and 1989. As in the case with stocks, engineering construction depreciation and reserves stock depreciation (real royalties) also differ. The volume of mineral reserves depreciation exceeded that of engineering construction capital stock by approximately $600 million per year on average during the period 1962–77. Thereafter, the volume of engineering construction stock exceeded the volume of mineral reserves by roughly $1.7 billion per year on average. However, over the entire 1962–89 period, the values were about the same.

Charts 1 and 2 compare GDP and NDP in the conventional and integrated accounts in current and constant prices based on (10) and (11). Most of the difference between integrated and conventional GDP depends on the difference between the service value of engineering capital stock and natural stock. Chart

TABLE 2

Flows and Stocks in the Conventional and Integrated Accounts at 1986 Prices:
Canadian Oil and Gas Industry

(Millions of Canadian Dollars)

Year	Own-Account Output	Discoveries	Engineering Construction Capital Stock	Reserves Stock	Engineering Construction Depreciation	Mineral Reserves Depreciation
1962	1,033.7	3,807.5	4,902.0	138,077.4	782.5	1,021.0
1963	1,175.0	3,439.7	5,235.3	140,018.3	841.7	1,096.0
1964	1,304.1	3,499.9	5,627.7	142,054.1	911.6	1,187.6
1965	1,600.2	7,146.4	6,226.0	147,825.1	1,002.0	1,276.4
1966	1,549.4	3,142.9	6,666.9	148,849.1	1,108.5	1,396.0
1967	1,407.0	3,947.1	6,889.8	150,112.2	1,184.1	1,533.4
1968	1,477.3	2,311.7	7,097.3	149,230.3	1,239.8	1,690.1
1969	1,513.5	4,321.8	7,317.1	157,382.4	1,293.7	1,876.2
1970	1,842.2	1,693.3	7,791.3	149,987.8	1,368.0	2,109.9
1971	1,620.4	3,311.5	7,973.5	151,524.2	1,438.3	2,266.7
1972	1,993.0	3,104.8	8,443.8	146,815.1	1,522.6	2,641.7
1973	2,157.3	3,484.7	8,966.9	135,060.5	1,634.2	2,991.0
1974	2,263.0	2,848.2	9,481.6	130,892.6	1,748.4	2,901.7
1975	2,461.6	1,969.1	10,075.7	126,378.9	1,867.5	2,559.4
1976	2,710.4	3,327.0	10,783.7	123,103.4	2,002.4	2,440.8
1977	3,209.8	4,483.7	11,818.7	120,793.0	2,174.8	2,472.7
1978	3,981.9	5,582.3	13,348.1	121,110.9	2,452.5	2,447.5
1979	5,444.9	8,427.9	15,921.8	124,765.6	2,871.2	2,743.7
1980	6,879.2	4,621.2	19,335.1	124,895.4	3,465.9	2,631.6
1981	6,329.2	2,722.7	21,621.9	121,881.7	4,042.3	2,461.7
1982	6,023.8	1,873.6	23,188.6	118,614.2	4,457.2	2,528.0
1983	5,926.2	2,131.4	24,343.7	117,566.6	4,771.0	2,619.1
1984	6,619.3	5,960.8	25,881.5	119,391.9	5,081.6	2,865.9
1985	7,284.1	2,058.0	27,645.2	116,200.0	5,520.4	3,074.0
1986	4,991.6	1,830.2	26,904.4	113,306.8	5,732.4	3,048.9
1987	3,786.9	1,881.0	25,104.3	110,642.7	5,587.0	3,194.1
1988	4,561.8	1,760.9	24,255.0	107,025.5	5,411.1	3,525.9
1989	3,840.5	1,373.9	22,842.1	102,741.2	5,253.4	3,472.0

1a shows that both GDP estimates remained fairly close during the period, which indicates that in current prices the existing accounting framework includes the full value of natural capital stock service.

Chart 1b compares the pattern of constant price GDP. As opposed to its current price counterpart, constant price GDP in the integrated accounts is significantly lower than its counterpart in the existing accounts over the entire period, mainly because the value of the services of engineering capital stock is higher than the value of the services of the natural capital. The existing accounts overestimate the service volume of natural capital.

Chart 2 compares NDP in current and constant prices based on (13) and (14). Different NDP values between accounting frameworks reflect the opportunity cost of natural capital and that of engineering capital stock. The pattern of NDP in Chart 2a differs little in both accounting frameworks, indicating that the existing accounts include the value of the economic depreciation of reserves. Chart 2b, which shows constant price NDP in the existing and integrated accounts, shows a converging trend. Existing accounts real NDP is greater than its counterpart in the integrated accounts during most of the period. This reflects a volume
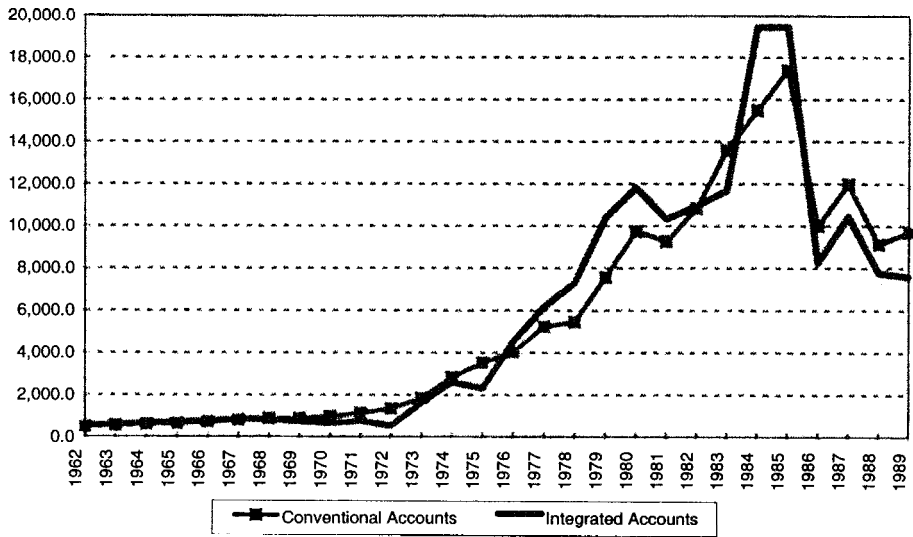
Chart 1a. Current Prices GDP of Canadian Oil and Gas Industry: (Millions of Dollars)
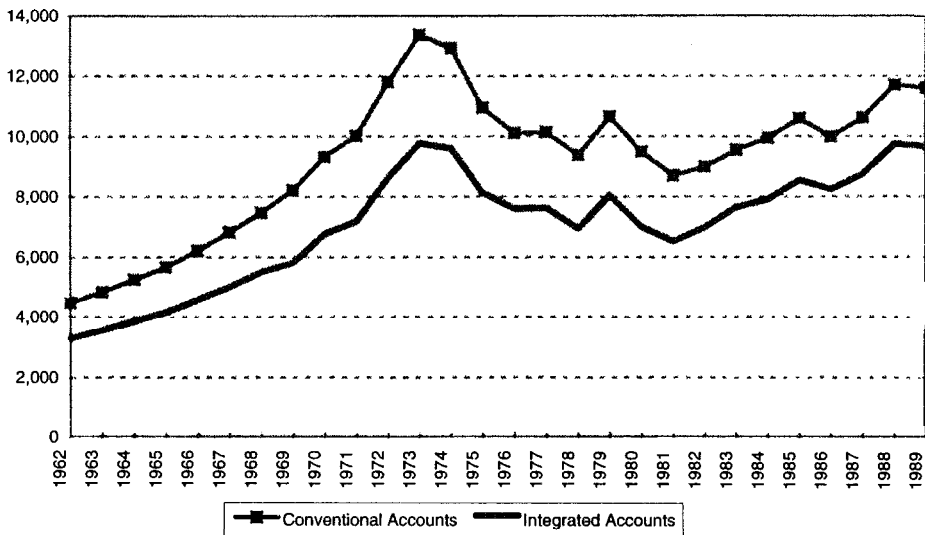

Chart 1b. GDP of Canadian Oil and Gas Industry at 1986 Prices: (Millions of Dollars)

associated with the opportunity cost of engineering construction capital that is higher than its natural capital counterpart. The volume of these two opportunity costs tends to converge after 1982. During this period, the opportunity cost of natural capital in constant prices tends to increase because of the decrease in the shadow price of oil and gas. In spite of a late-period convergence, the existing accounts overestimate NDP by $65 million per year on average.
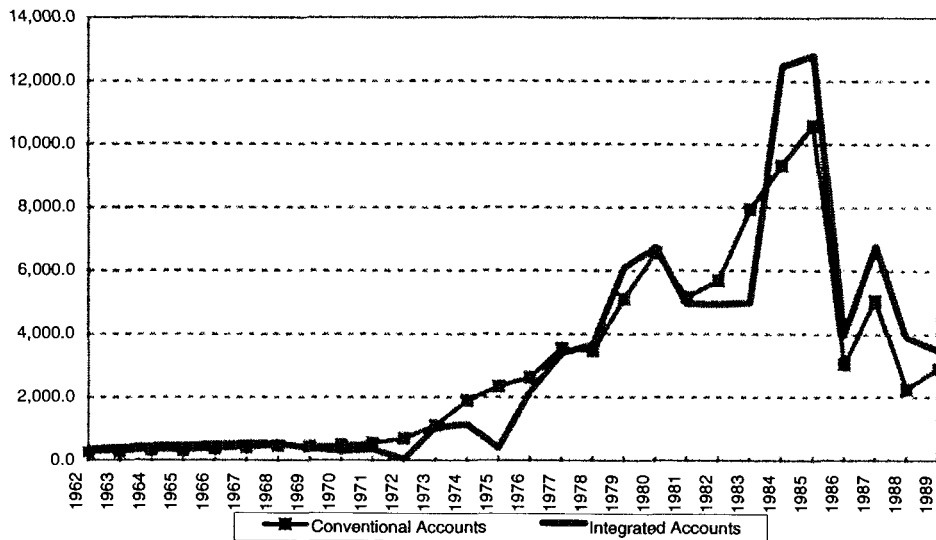
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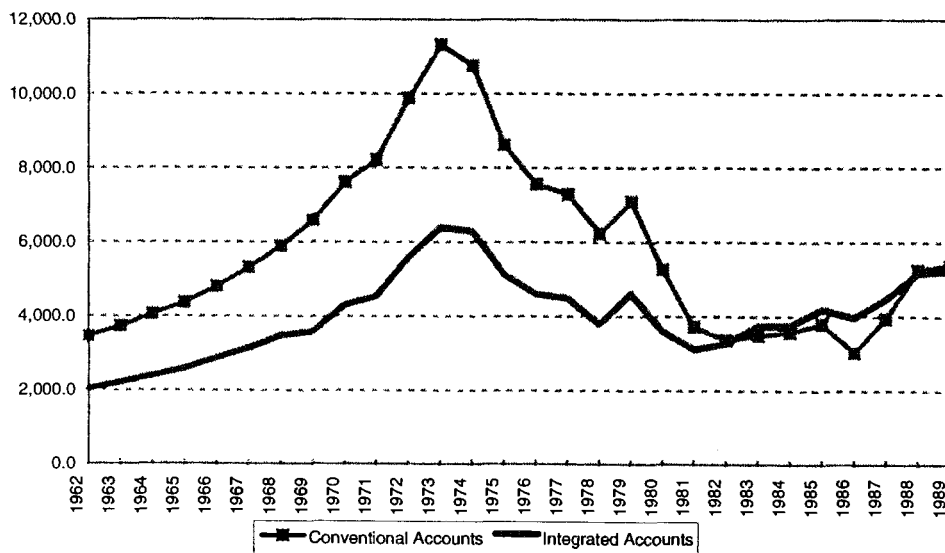Chart 2a. Current Prices NDP of Canadian Oil and Gas Industry: (Millions of Dollars)

Chart 2b. NDP of Canadian Oil and Gas Industry at 1986 Prices: (Millions of Dollars)

2. Multifactor Productivity Estimates

Chart 3 compares the MFP index of the conventional accounts with two alternative MFP indices for the integrated accounts. Conventional accounts productivity is based on $Q = f(K_{ME}, K_{BC}, K_{EC}, L, M, t)$ and that of the integrated accounts is derived from $Q = f(K_{ME}, K_{EC}, R, R^-, R_y, L, M, t)$ where Q is the real gross output of the oil and gas industry's extractive activity, K is physical capital,

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R is reserves-inventories, R^- is extraction, L is labour, M is intermediate inputs, and t is technological progress.

As Chart 3 shows, the conventional accounts MFP index (1962 = 100) reached a peak of 140 in 1972, after which it decreased to below its initial level, reaching about 60 in 1989. By contrast, the indices of productivity derived from the integrated accounts, at 120 in 1989, do not show technological regress over the 1962–89 period. The drop in conventionally measured productivity has been attributed to a rapid decline in natural resource quality. To test the importance of quality on productivity growth, we specify three alternative measures of the resource stock. The solid line index on Chart 3 employs a resource-inventory stock unadjusted for quality and a stock that is valued at marginal discovery cost. The line above employs the same resource volume adjusted by a natural resource quality index based on the hedonic approach (see Harchaoui, 1996). The impact of the hedonic quality index on productivity is small and has no long-term effect over the 1962–89 period. In another integrated accounts productivity index (not shown), the volume of reserves was calculated by the net accumulation of discoveries and extraction volumes, where both volumes were valued at marginal discovery cost. The resulting reserve-inventory stock shows a strong decline in quality, in the order of 50 percent over the period. The corresponding productivity index paralleled the movement of the other integrated account indices and reached 140 by the end of the period. By this measure, the effect of resource quality on integrated account productivity was to increase the productivity index in 1989 from 120 to 140, i.e. by 20 points. In contrast, the difference between conventional productivity (60 in 1989) and non-quality adjusted integrated productivity (120 in 1989) is in the order of 60 points. We therefore conclude that the effect of resource quality is a less important factor in explaining differences in productivity between the two accounting frameworks. The overall productivity decline in the conventional accounts can mainly be explained by conceptual problems associated with the treatment of natural resources.

VI. CONCLUSION

The argument that the national accounts ignore exhaustible natural resource flows and stocks in the measure of GDP, NDP, capital, and wealth is partly true. It originates in a conceptual imbalance of the accounts that leads to strongly negative productivity growth in mining industries and inappropriate measures of sustainable income. The perceived imbalance has led to propositions in the literature aimed at adjusting the value of GDP, NDP, and national wealth in the conventional accounts in order to compensate for the lack of the natural resource input. This paper shows that the accounting imbalance is not due to a lack of natural resource input in the accounts but that the accounts overlook natural resource inputs by treating them as produced commodities or as taxes when they should be treated as natural commodities.

Correcting for this shortcoming requires the introduction of new concepts into the accounts and corresponding measurement techniques. The new concepts are the discoveries of natural resources, the inventory of reserves, the extraction of natural resources, the depletion of the natural asset, and the distinction between
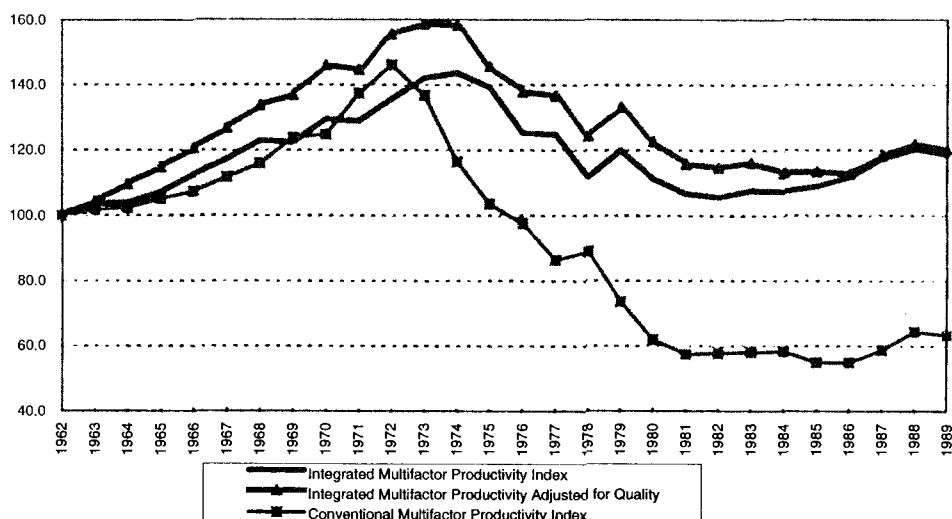
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Chart 3. Multifactor Productivity Indices (1962 = 100):
Canadian Oil and Gas Industry

durable and non-durable exhaustible natural resources. Incorporating these new concepts results in an accounting framework that completely integrates the flows and stocks of natural commodities with the flows and stocks of produced commodities. The new accounts also conceptually modify the conventional measures of industry GDP, NDP, and national wealth by including the missing contribution of natural resources to the value of economic production, national wealth, and productivity growth.

An empirical comparison between the existing and proposed accounting frameworks shows the extent to which the estimates of capital and national wealth in the traditional accounts include the value of the natural stock of reserves held by extractive industries, the extent to which capital formation includes the value of resource discoveries, and the extent to which the conventional estimates of economic depreciation include the value of resource extraction. We also find that the value of NDP resulting from the new accounts does not correspond to the conventional values corrected by the adjustment factor suggested by Hartwick, Solow and Weitzman.

The application of the proposed accounting framework to the Canadian oil and gas industry during the 1962–89 period indicates that most of the impact of the new accounting occurs primarily in the measures of multifactor productivity, real GDP, real NDP, and real wealth, and secondarily in the measures of current price GDP, NDP, and wealth. In the new framework, the Canadian oil and gas industry productivity index is always positive, growing at a long-term rate comparable to the average Canadian industry. We also found that changes in resource quality explain a small part of the productivity difference between the accounting systems presented here.

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REFERENCES

Bartelmus, P., C. Stahmer, and J. van Tongeren, Integrated Environmental and Economic Accounting: Framework for a SNA Satellite System, *Review of Income and Wealth*, 37, 111–48, June 1991.

Brown, G. M. and B. Field, Implications of Alternative Measures of Natural Resource Scarcity, *Journal of Political Economy*, 86, 229–43, 1978.

Cairns, R. D., The Economics of Exploration for Non-Renewable Resources, *Journal of Economic Surveys*, 4, 361–95, 1990.

Carson, C. B., Integrated Economic and Environmental Satellite Accounts, *Survey of Current Business*, April 1994.

Cas, A. and T. K. Rymes, *On Concepts and Measures of Multifactor Productivity in Canada, 1961–1980*, Cambridge University Press, Cambridge, U.K., 1991.

Halvorsen, R. and T. R. Smith, A Test of the Theory of Exhaustible Resources, *Quarterly Journal of Economics*, 123–40, 1991.

————, Substitution Possibilities for Unpriced Natural Resources: Restricted Cost Functions for the Canadian Metal Mining Industry, *The Review of Economics and Statistics*, LXVIII, 398–405, 1986.

————, On Measuring Natural Resource Scarcity, *Journal of Political Economy*, 92, 954–64, 1984.

Harchaoui, T. M., *Measuring Ricardian Rent Within and Between Canadian Oil Pools*, manuscript, p. 23, 1996.

Hartwick, J. M., National Wealth and Net National Product, *Scandinavian Journal of Economics*, 96, 253–56, 1994.

————, Natural Resources, National Accounting and Economic Depreciation, *Journal of Public Economics*, 43, 291–304, 1990.

————, Interregional Equity and the Investing of Rents from Exhaustible Resources, *American Economic Review*, 67, 972–74, 1977.

Hung, N. M., Natural Resources, National Accounting and Economic Depreciation: Stock Effects, *Journal of Public Economics*, 51, 379–89, 1993.

Lasserre, P., Discovery Cost as a Measure of Rent, *Canadian Journal of Economics*, 18, 474–83, 1985.

———— and P. Ouellette, The Measurement of Productivity and Scarcity Rents: The Case of Asbestos in Canada, *Journal of Econometrics*, 48, 287–312, 1991.

Lozada, G., Resource Depletion, National Income Accounting, and the Value of Optimal Dynamics Programs, *Resources and Energy Economics*, 17, 121–35, 1995.

Quyen, N. V., Exhaustible Resources: A Theory of Exploration, *Review of Economic Studies*, 58, 777–89, 1991.

Solow, R., On the Intergenerational Allocation of Natural Resources, *Scandinavian Journal of Economics*, 88, 141–49, 1986.

Stollery, K. R., Productivity Change in Canadian Mining 1957–1979, *Applied Economics*, 17, 543–58, 1985.

Weitzman, M. H., On the Welfare Significance of National Product in a Dynamic Economy, *Quarterly Journal of Economics*, 90, 156–62, 1976.