Using Ecosystem Accounting to Integrate the Environment in Measures of Multifactor Productivity

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Abstract

There is increasing recognition of the relevance of integrating environmental considerations within standard macroeconomic measures including GDP and national wealth and, by extension to measures of multifactor productivity (MFP). A range of approaches to measuring environmentally adjusted MFP (EAMFP) have been developed over the past decade which variously adjust the measure of output or recognize explicitly natural capital inputs. This article summarizes the main approaches to EAMFP and discusses their merits from a national accounting principles perspective, identifying some concerns on potential double counting of environmental contributions and effects. It then considers the potential of ecosystem accounting as described in the System of Environmental-Economic Accounting (SEEA) Ecosystem Accounting to offer an alternative framing for integrating the environment into economy-wide MFP measures.

The ongoing realities of climate change and the increasing pressure on biodiversity are significant risks to global economic and social systems. The number of reports highlighting the economic significance of these changing circumstances are numerous. To pick just one, in their 2020 report *Nature Risks Rising* (WEF, 2020), the World Economic Forum concluded that around 50 per cent of the global economy is moderately to highly dependent on nature. This, and other reports, highlight that ignoring the economy's connection to the environment or continuing to treat the environment as able to provide an endless supply of free environmental services is not

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just risky but poor economics. Developing an information set that supports more comprehensive economic analysis must be a core part of the collective response to our environmental challenges.

Over the past 15 years, significant steps have been taken in developing such an information set through the statistical standards embodied in the United Nations System of Environmental-Economic Accounting (SEEA). In 2012, the United Nations Statistical Commission adopted the SEEA Central Framework (UN *et al.*,2014) and in 2021 they adopted the SEEA Ecosystem Accounting (UN *et al.*, 2021). Together with a range of supporting materials, these statistical frameworks provide the structure for the organization of a wide range of environmental data that complements and extends the standard economic data organized following the System of National Accounts (SNA) (UN *et al*, 2010).

However, the development of structured environmental-economic information frameworks and datasets does not of itself lead to better and more integrated economic analysis. In the field of productivity analysis, most work remains focused on standard labour and multifactor productivity measurement and resolving a range of measurement challenges: some that are long-standing such as concerning public sector output and some emerging as the economic system continues to evolve, such as digitalization. A focus on incorporating environmental issues has not been central. Indeed, in a 2019 review article of the *Oxford Handbook of Productivity Analysis* (Reinsdorf, 2019), the word "environment" does not appear.

The explicit incorporation of environmental considerations into industry and economy wide productivity measures would support a more complete understanding of the factors that drive output and inputs growth and hence support the development of more integrated policy responses. Positively, there is an increasing number of examples of research on incorporating the environment into productivity analysis.

To further motivate this trend, Section 1 commences with a description of the main entry points that have been investigated in the development of environmentally adjusted multifactor productivity (EAMFP) measures. Section 2 then summarizes the key aspects of the SEEA framework that support the organization of information for the derivation of EAMFP. Section 3 discusses the challenges of connecting current EAMFP approaches to standard growth accounting theory and the national accounting principles that support implementation of the theory. Section 4 offers an alternative approach to economy wide MFP measurement that takes advantage of the extension to the SNA production boundary described in the SEEA Ecosystem Accounting. Section 5 demonstrates the alternative ecosystem accounting based approach with a stylized example. Section 6 concludes highlighting some key areas for future research.

Entry Points to Incorporating the Environment in Economy-Wide Productivity Analysis

A key driver in the development of measures of economy-wide MFP over the past 70 years has been the link between the growth accounting approach to the measurement of MFP and the ongoing compilation of the national accounts following the SNA. In basic terms, the growth accounting approach involves comparing the growth of output measured in quantity or volume terms to the growth of inputs, such as capital and labour, also measured in volume terms. To the extent that the growth in output is greater than the growth in combined inputs, then productivity growth, defined as MFP, is positive.

This approach relies on a number of assumptions including that producers behave efficiently (i.e. they minimize costs and/or maximise revenues) and that markets are competitive (see OECD, 2001 for more details). Under these assumptions, it is possible to construct an index of combined inputs using the factor income or cost shares as weights. That is, the index of combined inputs is calculated by weighting the changes in quantity of each type of input by the share of total costs for each input.

The link to national accounts emerges in two ways. First, a standard data release from national accounting systems are measures of volume indexes for output and inputs across different industries and products. Most commonly these volume indexes are estimated by deflating nominal measures of gross output and input costs by relevant price indexes. Subsequently, volume indexes of gross value added (GVA) can be derived. Second, another standard data release from national accounting systems are measures in nominal terms which provide the basis for the estimation of cost shares. Thus, the measures of gross output, GVA, intermediate consumption, compensation of employees, gross operating surplus and capital stock that are provided on an annual basis for most countries provides a rich and coherent data set for analysis of productivity.

Importantly, concerning measures in nominal terms there is an underpinning additive relationship between the inputs to production and the outputs of production. This allows the appropriate weighting of the contributions from labour and capital to GVA such that the residual, the unexplained growth in output that constitutes MFP in the growth accounting approach, to be meaningfully appraised.

Through input-output tables the national accounting system takes these additive relationships further supporting coherent measurement of the links between labour, capital and GVA and also supporting the measurement of KLEMS-based measures of MFP which do not use GVA as the measure of output but rather explicitly incorporate gross output and the various intermediate inputs such as energy, materials and services (E, M, S) in addition to inputs of capital (K) and labour (L).

In stylized terms we thus have the following accounting relationships that underpin the measurement of MFP. Note that, recalling the discussion above, the relationships described here (and in subsequent equations) must be measured using volume indexes for each component with MFP reflecting the growth rate in output, either value added or gross output, relative to the growth rate of combined inputs on the right hand side weighted using their cost shares.

$$\mathrm{GVA} = K + L + \mathrm{MFP} \tag{1}$$

$$\text{Gross Output} = K + L + E + M + S + \text{MFP} \quad (2)$$

These two equations are equivalent since GVA is equal to gross output less intermediate consumption (i.e. E + M + S).

As summarized in the OECD Productivity Manual (OECD, 2001: 18):

> "The economic theory of productivity measurement goes back to the work of Jan Tinbergen (1942) and independently, to Robert Solow (1957). They formulated productivity measures in a production function context and linked them to the analysis of economic growth. The field has developed considerably since, in particular following major contributions by Dale Jorgenson, Zvi Griliches and Erwin Diewert. Today, the production theoretical approach to productivity measurement offers a consistent and well-founded approach that integrates the theory of the firm, index number theory and national accounts."

Unfortunately, most current practices of productivity measurement omit the role of natural resources and ecosystem services as inputs into production and do not account explicitly for the effects of environmental pollution. By way of example, in measuring the productivity of the agricultural industry, some countries recognize land as an input but only in terms of its area; factors such as its quality (e.g. in terms of soil fertility) and the input of water are not considered. The depletion of mineral and energy resources is similarly omitted in assessing mining productivity (Syed, Grafton, Kaliappa and Parham, 2015).

This is not to say that the relevance of the environment in productivity analysis has been completely overlooked. Over the past 50 years there have been a range of efforts to examine the connections. There are four main entry points that have been used to adjust the standard growth accounting equations noted above.

Bad Outputs

The first entry point involves accounting for undesirable or bad outputs that arise from production processes such as air and water pollution often in the context of joint production models (Shephard (1970) and Färe *et al.* (1989)). This work has been most extensively developed by the OECD over the past 10 years. Brandt *et al.* (2014) develop their environmentally adjusted MFP (EAMFP) measure by deducting from GVA the effects of three air emissions sulphur oxides, nitrogen oxides and carbon dioxide. Subsequent work by Cardenas Rodriguez *et al.* (2018), Agarwala *et al.* (2022) and Cardenas Rodriguez *et al.* (2023) have progressively expanded the range of air emissions and the level of industry detail at which calculations are undertaken. In all of these cases the measure of an environmental bad is deducted from GVA in the MFP equation. Thus, in simple terms

$$\text{GVA} - \text{Environmental bads} = K + L + \text{MFP} \quad (3)$$

Natural Capital Inputs

The second entry point concerns recognition of natural capital inputs. This entry point recognizes that conceptually the K in the MFP equation reflects the contribution of both produced and natural capital. For many years a number of countries have included land as an input to the capital contribution in agriculture but, in terms of standard practice, this has not been extended to other industries where natural capital is a fundamental input.

Positively, work by Brandt *et al.* (2013) and Topp and Kulys (2014) explain well the relevance and potential of adjusting standard productivity measures for natural resource inputs. Brandt *et al.* focus on the user costs of depleting mineral and energy resources in assessing productivity of the mining industry. Topp and Kulys consider also rainfall as an input to agriculture and noted the shift in Australia from using rain-fed dams to underpin water supply towards increasing use of produced capital such as via desalination and water recycling. Hamilton *et al.* (2018) build on the work of Brandt *et al.* (2013) in the context of the wider work of the World Bank in measuring national wealth.

The most recent additions to this suite of natural capital input adjustments are included in the latest version of the OECD EAMFP model (Cardenas Rodriguez *et al.*, 2023) which includes natural capital inputs covering land resources, non-renewable mineral and energy resources, biological resources (timber and fish), three ecosystem services (watershed protection, non-wood forest products and coastal flooding protection) and three renewable energy resource inputs (hydro, wind and solar).

The resulting simple growth accounting equation is reflected as

$$\text{GVA} = K^P + K^N + L + \text{MFP} \qquad (4)$$

where K^P refers to produced capital and K^N refers to natural capital.

In this framing, the effect of including K^N is to more appropriately recognize the role of natural capital recognizing that the non-labour share is the same in both equations (1) and (4). In accounting terms this represents the partitioning of gross operating surplus into a return to produced capital and a return to natural capital. MFP will be affected to the extent that the volume growth rate of natural capital is different from the growth rate of produced capital.

Since the natural capital inputs are treated as non-produced (e.g. arising from the discovery of a mineral deposit) there is no associated change in GVA. However, changes in the stock of natural capital may have effects on the cost of natural capital but the growth in K^N, and hence MFP, is driven primarily by rates of extraction and use of natural capital rather than overall changes in the size of the physical stock.

Environmental Expenditures

A third entry point to adjusting the growth accounting equation has been investigated in Agarwala *et al.* (2022). They propose a positive adjustment to GVA by treating environmental expenditures as additional output as a proxy for the improvements in environmental outcomes that arise from undertaking this expenditure. Put differently, without recognizing an increase in gross output, expenditure on the environment will reduce MFP growth, all else being equal. The effect of raising the measure of gross output leads to the productivity equation shown in equation (5).

$$\text{GVA} + \text{Environmental expenditures} = K + L + \text{MFP} \quad (5)$$

Combinations of these three entry points are also possible and indeed the full OECD EAMFP model combines entry points 1 and 2 as reflected in equation (6) using the stylized notation applied here.

$$\text{GVA} - \text{Environmental bads} = K^P + K^N + L + \text{MFP} \quad (6)$$

Conditional Measures of MFP

A fourth entry point is formulated in Schreyer (2021). That article returns to equations (1) and (2) and, recognizing that the underlying relationships in growth accounting are linked to production theory, describes a cost function that is conditional on ecosystem services. In this case there is no necessary accounting or additive relationship between the ecosystem services and the standard combined inputs but an alternative measure of MFP, conditional on changes in the flows of ecosystem services, is still derived. This entry point is not considered further in this article since it has no direct link to the extended accounting approaches that are the focus here, but is recognized to highlight the range of different approaches that might be developed.

Environmental Adjusted MFP for Agriculture

Separately from the work on economy-wide measures of MFP, experts in measuring the agriculture industry have well established measures of productivity. The approaches range from farm-level analysis to national and international level studies and encompass econometric and non-parametric approaches to MFP measurement in addition to growth accounting. In 2015, the OECD commenced a program of work on improved measures of agricultural MFP and papers by Hoang (2015) and Kuosmanen (2015) summarized the state of play.

Generally, the focus of environmentally-adjusted agriculture MFP measures has been to consider adjustment of standard MFP measures for specific environmental factors including land, the impacts of nitrogen (N) and phosphorous (P), residuals and by-products from agricultural activities, including GHG emissions, and the impacts of changes in weather patterns, for example due to climate change. This work has generally reflected the use of the first two entry points described above, i.e., adjusting for bad outputs and adjusting for natural resource inputs, primarily land.

This article does not attempt a wider review of these methods except to note that there is a close conceptual link between the approaches used by agricultural experts in, for example, the United States (Ball *et al.*, 2014), Canada (Cahill & Rich, 2012) and Australia (Zhao *et al.*, 2012) and the economy-wide growth accounting described above. And there is associated work to consider environmental-adjusted measures of agricultural productivity that reflect the types of adjustments just described as recently summarized by OECD (2022). Given these links, and building on the ideas of Obst and Eigenraam (2017) concerning environmentally adjusted MFP measures for agriculture, the discussion in this article should be broadly amenable to consideration by those industry experts.

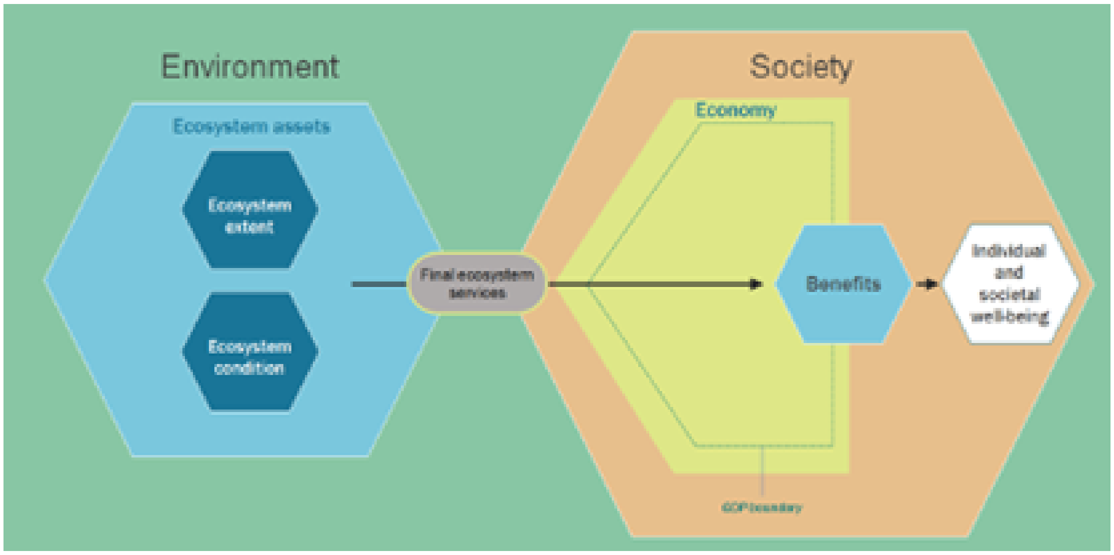
Expanding the Information Set to Support EAMFP

The need to better integrate measures of the environment within the national accounts framework was increasingly recognized through the 1970s and 1980s (Bartelmus, 1987; Ahmad *et al.*, 1989). Consistent with a request from the first United Nations Conference on Environment and Development held in Rio de Janeiro in 1992 (United Nations, 1992), the United Nations Statistical Division led the drafting of the first international document on environmental-economic accounting (United Nations, 1993). This document, *Handbook on National Accounting: Integrated Environmental and Economic Accounting*, became known as the System of Environmental-Economic Accounting or SEEA.

Over the past 30 years there has been a progressive broadening of focus in SEEA related work. Through the 1980s and early 1990s, the primary focus was on extensions and adjustments to gross domestic product (GDP), for example measures of depletion and degradation adjusted GDP, and recording environmental expenditures. Through the 1990s this focus broadened to consider how accounting approaches can be used to organize physical information on environmental stocks and flows such as water, energy and waste. Also through the 1990s, and in parallel with similar developments in the SNA, the SEEA delved deeper into accounting for individual natural resources including mineral and energy resources, timber, fish and land. This combination of topics was embodied in the first international statistical standard for environmental-economic accounting adopted in 2012, the SEEA Central Framework (UN *et al.*, 2014).

The more recent and conceptually most progressive development concerns ecosystem accounting as a complement to accounting for individual environmental stocks and flows in the SEEA Central Framework. Work on the SEEA Ecosystem Accounting (UN *et al.*, 2021) commenced in 2011 and took advantage of developments in the measurement of ecosystem services, such as presented in the report of the United Nations *Millennium Ecosystem Assessment* (MA, 2005), the original The Economics of Ecosystems and Biodiversity (TEEB) study (TEEB, 2010) commissioned by the German Environment Minister and the EU Environment Commissioner, and the National Ecosystem Assessment of the United Kingdom (UK NEA, 2011). In 2021, the SEEA Ecosystem Accounting framework (Figure 1) was adopted by the United Nations and notwithstanding its short life, it is now recognized across the private and public sectors as the leading framework for linking the economy and the environment for the

Figure 1: General Ecosystem Accounting Model (SEEA EA Figure 2.1)



Source: UN *et al.*, 2021

purposes of economic and financial analysis. [2]

Both the SEEA Central Framework and SEEA Ecosystem Accounting are connected to the SNA through their application and adaptation of national accounting principles and treatments. Indeed, the logic driving the development of the SEEA is (i) that the SNA's accounting for the environment is insufficient; and (ii) that highlighting the significance of the environment may be best achieved by mainstreaming environmental information via the standard framework for economic measurement. In the context of productivity analysis, since it is the data from the SNA that underpins the standard measures of MFP, it is equally the concepts in the SEEA that can provide a fundamental building block towards environmentally- adjusted measures of MFP.

Ecosystem accounting is focused on accounting for ecosystem assets – their extent (or size), their condition (or health) and the ecosystem services they supply. The full ecosystem accounting model is described at length in Chapter 2 of SEEA Ecosystem Accounting and readers are referred to that document for a detailed description.[3]

Five key features of the ecosystem accounting model are noted:

- **The delineation of spatial areas.** Within a broader ecosystem accounting area (e.g. a country, state, water catchment), each ecosystem asset (e.g. a grassland, forest, coastal dune, coral reef, cropland) is delineated as a distinct spatial area. For the purposes of integrating ecosystem information about ecosystem assets with standard economic accounts and

2 For additional context on the development of the SEEA Ecosystem Accounting, see Edens *et al.* (2022).

3 The references section of the SEEA Ecosystem Accounting provides an extensive listing of the literature on which the various aspects of the ecosystem accounting model have been based. This includes research in relation to ecosystem condition, ecosystem services, ecological economics, geospatial statistics and national accounting.

productivity measures, it is most useful to consider each ecosystem asset as a type of economic unit, analogous to a single business or household. In effect, ecosystem accounting extends the set of units considered in an accounting framework beyond the standard economic units.

- **Measuring the condition of ecosystem assets.** Each ecosystem asset has numerous characteristics (such as climate, soil, vegetation, species diversity, etc.) and performs various ecosystem processes. The integrity and functioning of the asset is measured by its condition. It is the decline in overall condition, in biophysical terms, that underpins the measurement of ecosystem degradation.

- **Measuring the flow of ecosystem services.** Each ecosystem asset supplies a basket of ecosystem services that are consumed by different economic units including businesses, households and governments. These flows between ecosystems and economic units can be recorded in supply and use tables analogously to flows of goods and services between industries. The coverage of ecosystem services includes provisioning services (e.g. food, fibre, water), regulating and maintenance services (e.g. air filtration, pollination, water flow regulation, global climate regulation) and cultural services (e.g. recreation).

- **Relating ecosystem services to standard measures of economic activity.** The supply of all ecosystem services is outside the production boundary of the SNA as they are considered to arise from natural processes (SNA 2008, 6.24). At the same time, many ecosystem services contribute to the production of goods and services that are included in the SNA production boundary, for example the contribution of water to rice production. To understand the impact on measures of GDP, it is necessary to recall that GDP is a measure of value added – i.e. gross output less intermediate inputs. Thus, where ecosystem services contribute to existing measures of gross output (e.g. to the production of crops), the net effect on GDP and MFP of recording both the supply and use of ecosystem services is zero, since the ecosystem services are considered both as additional outputs (of the ecosystem asset) and additional inputs (of the farmer).[4] Where ecosystem services are not an input to the production of goods and services included in the SNA production boundary, the additional output that is attributable to ecosystem assets will increase measures of both economy-wide gross output and value added.

- **The use of exchange values.** The ecosystem accounting model reflects relationships between stocks and flows that exist without regard for the unit of measurement. Thus, in concept, the accounting relationships can be reported in both physical and monetary units. Measurement in monetary terms requires the use of various valuation techniques since prices for ecosystem services and assets are not directly observed in markets as for standard economic products. To support connection

4 Note that it is by recognizing ecosystem services as both outputs (of ecosystem assets) and inputs (to farming units) that double counting is avoided. The treatment is exactly analogous to the treatment of outputs and inputs through the supply chains recorded in standard input-output tables.

to the data in the national accounts, measures in monetary terms are recorded at their exchange value by estimating (using non-market valuation methods) the prices at which a willing buyer and willing seller would complete a transaction in a single ecosystem service.

These five key elements of ecosystem accounting provide the conceptual basis for extending the current approaches to measuring MFP.

Evaluating EAMFP Measures in Relation to Accounting Data

Starting from the OECD's EAMFP model as expressed in equation (6), there are direct connections that can be made to the SEEA framework as summarized above. Purely from the perspective of providing data inputs to the calculation of EAMFP, the following SEEA accounts will support the compilation of robust data that are consistent with standard national accounting treatments and with other components of the EAMFP calculation, namely GVA, produced capital and labour.

- SEEA Central Framework Air emissions accounts
- SEEA Central Framework Land accounts
- SEEA Central Framework Natural resource accounts for mineral and energy resources, timber resources, fish resources
- SEEA Central Framework Energy accounts for renewable energy resources
- SEEA Ecosystem Accounting Ecosystem services supply and use tables.

While the SEEA framework can supply the data ingredients, there are two significant concerns relating to the underlying relationship between the components within equation (6). Recall from section 2 that a key feature of the application of the growth accounting approach to the measurement of MFP has been application of the additive relationships between the output and input variables that are inherent in the national accounts system, including the input-output tables. The concerns, one relating to the treatment of ecosystem services in the measurement of natural capital inputs and one related to environmental bads, arise because the underlying additive accounting relationships are not maintained in the EAMFP equation.[5]

Before discussing these concerns, note that, the additive accounting relationship can be maintained provided that the calculation includes only those natural capital inputs which contribute directly to GVA and gross output as defined in equations (1) and (2), for example, inputs of minerals, timber and fish. In the context of the OECD EAMFP model, this direct link is evident for all inputs from non-renewable fossil fuel and mineral resources (reflected in output of the mining industry), for inputs of renewable energy resources (reflected in output of the electricity industry), for inputs from cropland and pastureland, from timber resources and from marine capture fisheries (all reflected in outputs of the agriculture, forestry and fish-

5 Note that the discussion here does not encompass an evaluation of the fourth entry point noted in the first section of the article from Schreyer (2021).

eries industries). All of these natural capital resources are referred to in the SEEA Central Framework as individual natural resources.

The accounting relationship involving natural capital and other inputs has been well developed in the capital accounting literature and is evident in the work cited above, for example, Brandt *et al.* (2013) and Hamilton (2018). It reflects a much wider literature on this topic in the context of wealth accounting [6] The application of this theory to national accounting and the SEEA has been embodied in work by Schreyer and Obst (2015) and research conducted separately by Fenichel and Abbot (2014) who applied the underlying Jorgenson capital accounting framework to the valuation of natural capital, in essence finding that an analogy between accounting for natural and produced capital can be established.[7]

Evaluating the Inclusion of Ecosystem Services

The first concern about additivity in the EAMFP equation relates to the way in which ecosystem services have been included. Cardenas Rodriguez *et al.* (2023) explain that they have included three ecosystem services – non-wood forest products and watershed protection from forests and coastal flooding protection from mangroves – and note that they would ideally have included many other ecosystem services including recreation, habitat and species protection and cultural and existence values but data and valuation limitations prevented their inclusion.

It is certainly the case that ecosystem services can be incorporated into the measurement of natural capital following the wealth accounting theory just referenced. Indeed, Eigenraam and Obst (2018) explain the analogous conception of ecosystem services and capital services from produced capital. However, incorporation of ecosystem services within a wider model must consider (a) overlap with other measures of natural capital; and (b) links to the production boundary of the SNA.

With respect to point (a), the SEEA makes clear that accounting for ecosystem assets and accounting for individual natural resources are complementary areas of measurement, not additive. Thus, for example, the value of a forest will encompass its supply of a range of ecosystem services including the supply of wood. There is thus a potential overlap that needs to be managed, i.e. values of individual natural resources (e.g. timber resources) and ecosystem assets (e.g. forests) cannot be simply added together. The current selection of ecosystem services in the OECD EAMFP appears to avoid this overlap but this issue will need to be recognized in future work.

6 See, for example, Hamilton and Clemens (1998), Dasgupta and Maler (2000); Arrow *et al.* (2012), Hamilton (2015) and Diewert and Fox (2015).

7 Strictly, ecosystem accounting does not include inputs from non-renewable resources or inputs from renewable energy sources since these inputs are considered abiotic flows rather than ecosystem services. However, in a wider accounting context and for the purposes of productivity analysis, abiotic flows and ecosystem services can be aggregated within the same accounting framework and in the following discussion the two inputs are accounted for analogously.

A related issue is where ecosystem services are intermediate (for example pollination as an input to crop provisioning or nursery services as an input to fish provisioning) since here simple aggregation of all services will miss the inherent ecosystem supply chain (input-output type) interactions and hence overstate the overall ecosystem contribution.

With respect to point (b), the OECD EAMFP approach implicitly assumes that the ecosystem services are contributions to the production of goods and services that are within the SNA production boundary. This is appropriate in the context of non-wood forest products (e.g. mushrooms, berries, maple syrup, cork, bush meat), but cannot be assumed in the case of watershed protection or coastal flooding protection. That is to say that these two ecosystem services contribute to benefits received by people and society that are beyond the scope of the goods and services measured within GDP. To the extent that this occurs, then the natural capital inputs in equation (6) will not be matched by a corresponding output and, all else equal, EAMFP will be understated.

Evaluating the Deduction of Environmental Bads

The second concern relates to the deduction of environmental bads. No doubt there is an economic argument to support the case that measured output should be adjusted to take into consideration the negative externalities arising from production. However, in accounting terms it is not a simple matter of deducting bad outputs from good outputs and indeed, the SNA is quite explicit about not accounting for externalities and GDP not being interpreted as a measure of welfare.

The accounting challenge arises because the additive accounting relationships depend on recording transactions between economic units. In a national accounting sense this requires that there is both a supply and a use for each transaction. In the case of pollution, while the flow of pollutants no doubt comes from an economic unit, there is no corresponding receiver. In effect the question of the environmental bad is being considered from the perspective of one unit only and national accounting requires a more comprehensive framing.

A particular concern in simply deducting environmental bads from output is that it may double count the effects. Consider the case where air pollution by one company leads to increased costs to nearby building owners either through higher maintenance costs or lower rentals incomes. In the economy-wide accounts these increased costs to the building owner will be reflected in measures of GVA – i.e. GVA will be lower all else being equal. Additional deduction of bad outputs from the GVA of the polluter would overstate some of the effect of the pollution. The extent to which there is a double counting of the negative effects of the air pollution (or any other environmental bad) will be dependent on a wide range of contextual factors. Indeed, to the extent that the pollution has no effect on other economic units, then the question must be raised as to why the release of the pollutant should be considered as a negative.

The approach of Brandt *et al.* (2013) addresses this issue to some degree by applying a private valuation of the "bads" by weighting them with the measure of "good" output using marginal abatement costs as seen by the producer. Inherent in this approach is the assumption that increasing good output necessarily involves increasing bad output. This in turn has the effect of constraining the concerns described above to the polluter. At the same time however, the approach then does not reveal the wider implications of bad outputs on the wider economy.

The key point here is that care is needed in using an approach that deducts bad outputs and, in doing so, considering the accounting relationships between inputs and outputs can be an important tool in developing and interpreting alternative approaches.

Note that this concern is not limited to the current OECD EAMFP model, but is relevant in considering all approaches where GVA is adjusted by an environmental bad as part of an extended growth accounting approach.

An Alternative Approach to Extending MFP Measures

A common feature of the environmentally-adjusted measures described in Section 2 is that all adjust GVA and hence the measure of output in the MFP equation is equal to value added rather gross output. This is significant since without a full articulation of inputs and outputs across all industries, the connection to the environment is only seen in terms of either (a) a natural capital input; or (b) a negative impact on the environment. Consequently, and as introduced in Section 3, connections between industries (e.g. the effects of pollution on other activities) or between natural inputs and produced inputs (e.g. the trade-offs between fertilizer and soil fertility) cannot be examined in the richness that the underlying economic theory would prefer. This section describes an approach that embodies this richness and incorporates the additive accounting relationships that are considered essential in applying growth accounting approaches. The approach builds on initial thinking proposed by Obst and Eigenraam (2017) in the context of agricultural productivity.

At the heart of the alternative approach is the combination of the KLEMS approach to MFP reflected in equation (2) and the ecosystem accounting framework depicted in Figure 1. Recalling that the measurement of MFP will require calculation of volume indexes for combined outputs and inputs weighted by their nominal output and cost shares, equation (7) presents the core Ecosystem MFP model

$$\begin{aligned}\text{Gross Output (SNA)}+\text{Output (Ecosystem services)} &= \\ K^P + K^E + K^{NR} + L + E + M + S &+ \\ \text{Input (Ecosystem services)} + \text{MFP} \quad (7)\end{aligned}$$

where K^P refers to produced capital, K^E refers to ecosystem assets (encompassing renewable resources such as timber and fish), K^{NR} refers to non-renewable natural resources and L, E, M and S are as per the standard KLEMS model.

In short, the Ecosystem MFP model extends the production boundary of the SNA and allows explicit recognition of all ecosystem service contributions (via K^E) and records all flows of ecosystem services between ecosystems and economic units arising as a result of these ecosystem service contributions (via the inclusion of outputs and inputs of ecosystem services). While this may appear to "over-record" the flows associated with ecosystem assets, the example below demonstrates the relevance of this all-encompassing approach.

In relation to the two concerns raised above, this approach will ensure (i) that there is no double counting of components of natural capital since ecosystems assets (encompassing renewable natural resources such as timber and fish) and non-renewable natural resources are clearly distinguished; (ii) that there is a balanced reflection of ecosystem service contributions in relation to both inputs and outputs; and (iii) supports accounting for the economy-wide effects of environmental pollution via either reduced flows of ecosystem services (as a result of the degradation of ecosystem assets) or through changes in measures of gross output or intermediate consumption (i.e. E, M and S).

The approach also has the benefit of providing a framing of connections to environmental stocks and flows that is exhaustive subject to data availability. That is to say that conceptually the set of ecosystem assets will cover an entire geographic territory in an analogous manner to a business register providing a complete coverage of economic units. Note that the set of economic units that constitutes an economy is defined by those units that are resident in a country and the associated geographic territory is consistent conceptually with that used to establish the set of ecosystem assets.[8]

Although the accounting basis for the ecosystem MFP model can be described clearly, it must be recalled that the growth accounting approach relies more fundamentally on production theory such that the difference between the growth in output and the growth in input can be legitimately interpreted as a measure of productivity. Of particular note is the relevance of assumptions concerning producer behaviour in terms of minimising costs or maximizing revenues. An important concern therefore is how the inclusion of ecosystem assets and ecosystem services may be linked to this production theory and associated assumptions.

While this issue definitively requires further research, two points are noted. First, a not unrelated issue arises in considering the inclusion of non-market production, for example of health and education services, in measures of economy-wide productivity. The discussion of relevant assumptions for this type of non-market activity may be more developed in part because there are definable economic agents involved but challenges remain.

Second, a possible way forward with respect to ecosystems is to consider that each ecosystem asset has an associated steward (analogous to the executive board of a company) that acts on behalf of the ecosystem

8 Accepting that in practice small differences may emerge, for example concerning territorial enclaves and embassies.

Table 1: Standard Supply and Use Table for Apple Farmer (currency units, e.g. dollars)

	Apple farmer	Other industries	Household final consumption	Total
Supply table				
Apples	800			800
Apple products		2000		2000
Fertilizer		200		200
Fuel		150		150
Total output (1)	800	2350		3350
Use table				
Apples		800		800
Apple products			2000	2000
Fertilizer	200			200
Fuel	150			150
Total input (2)	350	800	2000	3350
Gross value added (3=1-2)	450	1550	na	2000
Labour input: Wages and salaries (4)	150	600		750
Gross operating surplus (5=3-4)	300	950		1250

Source: Author's compilation

in making exchanges of ecosystem services with economic units. This framing might be considered implicit in the methods used in environmental economics to identify the willingness of economic units to pay for ecosystem services, and inherent in the design of environmental markets and related payments for ecosystem services schemes. To the author's knowledge these potential connections between ecosystems and production theory have not been developed.

Demonstrating the Ecosystem MFP Model

To demonstrate the links between ecosystem accounting and the Ecosystem MFP measure, the following stylized example is presented starting from the changes that would be reflected in the standard supply and use table entries for an apple farmer who utilizes pollination services. To provide a starting point for the example, Table 1 shows the entries in the standard supply and use table. No pollination services are recorded and there is simply crop outputs (in this case apples), and purchased intermediate inputs of fertilizer and fuel.

Incorporating "Direct" Ecosystem Services into MFP Calculations

The incorporation of ecosystem services into MFP calculations should be considered in a number of stages where different types of ecosystem services are progressively included. The most straightforward inclusion concerns ecosystem services where there is the direct use of an ecosystem by an eco-

Table 2: Extended Supply and Use Table for Apple Farmer for Direct Ecosystem Services (currency units, e.g. dollars)

	Apple farmer	Other industries	Ecosystem asset: Forest	Household final consumption	Total
Supply table					
Apples	800				800
Apple products		2000			2000
Fertilizer		200			200
Fuel		150			150
Ecosystem services: Pollination			200		200
Total output (1)	800	2350	200		3350
Use table					
Apples		800			800
Apple products				2000	2000
Fertilizer	200				200
Fuel	150				150
Ecosystem services: Pollination	200				200
Total input (2)	550	800	0	2000	3350
Gross value added (3=1-2)	250	1550	200	na	2000
Labour input: Wages and salaries (4)	150	600	0		750
Gross operating surplus (5=3-4)	100	950	200		1250

Source: Author's compilation

nomic unit. Using agriculture as a starting point, examples of ecosystem use include the abstraction of water for irrigation, the pollination of crops by wild pollinators, grass eaten by livestock and the absorption of soil nutrients in crop growth. For each of these types of ecosystem service there is an associated flow that reflects the flow of capital services that can be included in Ecosystem MFP formula.

In the example, in Table 2, the supply and use table is extended to record the imputed value of output of pollination services supplied by the neighbouring forest ecosystem and the use of those ecosystem services by the apple farmer. The result is that the value added that was previously attributed solely to the apple farmer is now partitioned across two producing units – the apple farmer and the forest ecosystem asset.

From an MFP perspective, we see that additional inputs (i.e. the pollination services) have been explicitly recorded in the production function of the apple farmer and can now be incorporated into the calculations.

In this example, the use of pollination services is recorded in a manner analogous to the leasing of machinery from a rental company. An alternative, but entirely consistent, recording might be considered if the ecosystem asset supplying the services was considered to be under the control of the apple farmer. This is implicitly the assumption in the OECD's EAMFP. In this case the flow of ecosystem services would not be recorded as a part of intermediate inputs but rather as a flow of capital services which would, in effect, be shown in a

Table 3: Extended Supply and Use Table for Apple Farmer for Direct and Indirect Ecosystem Services (currency units, e.g. dollars)

	Apple farmer	Other industries	Ecosystem asset: Forest	Household final consumption	Government final consumption	Total
Supply table						
Apples	800					800
Apple products		2000				2000
Fertilizer		200				200
Fuel		150				150
Ecosystem services: Pollination			200			200
Ecosystem services: Global climate regulation			250			250
Total output (1)	800	2350	450			3600
Use table						
Apples		800				800
Apple products				2000		2000
Fertilizer	200					200
Fuel	150					150
Ecosystem services: Pollination	200					200
Ecosystem services: Global climate regulation					250	250
Total input (2)	550	800	0	2000	250	3600
Gross value added (3=1-2)	250	1550	450	na		2250
Labour input: Wages and salaries (4)	150	600	0			750
Gross operating surplus (5=3-4)	100	950	450			1500

Source: Author's compilation

partitioning of the apple farmer's gross operating surplus, together with the capital services of any machinery and equipment for example.

The benefit of partitioning the ecosystem asset as a producing unit is that it facilitates both understanding inputs to the apple farmer but also the recording of other ecosystem services that may be supplied by the partitioned ecosystem asset, for instance global climate regulation services by the forest (Table 3). Allowing for multiple services and multiple beneficiaries in the measurement of MFP is core benefit of using the Ecosystem MFP approach.

Incorporating Broader Benefits Arising from Agricultural Land

As just introduced, a third stage of potential extension is recognizing that there will be a range of positive externalities that could be considered in understanding the full production function and relevant trade-offs. Thus, the incorporation of ecosystem services can be extended to include, for example:

- The global climate regulation services (via carbon sequestration and retention) of ecosystems which provide benefits globally,
- The role that ecosystems play in the regulation of water flows within a water catchment and
- The cultural benefits obtained from the good management of landscapes.

Table 3 incorporates just one additional ecosystem service, global climate regulation services, thus adding rows to the supply and use tables and recording supply by forest ecosystems and use by general government (following the convention for recording the use of these services in the SEEA Ecosystem Accounting). Note that total gross output and total value added of the system as a whole are increased through this addition since the production and. consumption of global climate regulation services concerns output that is outside the SNA production boundary.

From an MFP perspective, this extension has no effect on aggregate MFP since both outputs and inputs are increased equally. However, this extension does allow a richer understanding of the role of natural capital to be reflected, in this case for forest ecosystems. For this extension and the previous extension concerning pollination services, the incorporation into measures of MFP will require estimation of volume indexes showing the growth in ecosystem services together with estimates in nominal terms (as presented in Tables 2 and 3) to provide weights for the derivation of combined output and combined input measures.

Incorporating the Effects of Environmental "Bads"

A fourth stage in the incorporation of ecosystem services is facilitating analysis of the effects of environmental "bads" as undertaken in a number of approaches to EAMFP. Notwithstanding the accounting concerns raised in the previous section, it is noted that one motivation for the deduction of bads from output is that the negative effect is attributed directly to the polluter – in effect it is a polluter pays framing of the analysis. From an accounting perspective however, the effects of negative external events are not treated in this way, unless of course the pollution affects the polluter. Put differently, accounts record the first round, direct implications of external effects on stocks and flows across all economic units and, in the context of ecosystem accounting, all ecosystem assets. What is not undertaken is any attribution of blame for those changes in stocks and flows, i.e. accounting does not directly provide a polluter pays perspective. When considered from the perspective of economy-wide measures of MFP, it is likely that in most cases of air and water pollution there will be the scope for all of the effects in terms of increased costs or reduced revenues to be captured, even when not attributed to a causing unit.

This capacity of an economy wide MFP measure to capture a full range of negative external effects is reinforced through the extension to record ecosystem services since many of the effects of pollution will relate to loss in environmental quality and the subsequent loss of ecosystem services contributions. For example, pollution of water bodies may lead to water supply companies spending more on water treatment to support the water purification services received from ecosystems. Thus, from the perspective of economic units affected by environmental bads, the Ecosystem MFP will provide a direct and more encompassing measure of the changes in their productivity as a result of pollution. At the same time, since a measure of industry productivity based on a polluter pays framing may be relevant in some contexts, additional analysis and reorganization of data will be required that is beyond the Ecosystem MFP framing.

Research Challenges and Future Directions

Overall, the incorporation of ecosystem services into the derivation of MFP should support a more extensive analysis of economy wide productivity. In particular, it is highlighted that there is the potential to reflect, in the measures of MFP, the results of investments in ecosystem management and restoration – for example via nature-based solutions - as part of the productivity equation both in the context of measuring industry outputs and in the broader benefits that positive ecosystem management can provide.

There are two key challenges in incorporating ecosystem services. First, there is challenge of understanding and measuring the relationship between the physical flows of ecosystem services and the associated outputs. Commonly, there are no simple linear relationships involved with the supply of ecosystem services. The flows will be dependent on a range of factors including the relative condition of the ecosystem asset (and neighbouring assets), and the extent to which produced inputs are used, for example the application of fertilizer and pesticides or the supply of infrastructure to support recreation in national parks. However, while the precise articulation of the link between ecosystem services and output may be difficult to measure, this challenge also arises for produced capital (although perhaps to a lesser extent) whereby assumptions about the link between assets and capital service flows are made following generalized models (OECD, 2001).

The second challenge lies in estimating the cost share relevant for these inputs. Where ecosystem services flow directly into the production of outputs that are included in standard measures of industry value added, in concept the value of the ecosystem service inputs should be incorporated implicitly in estimates of gross operating surplus, i.e. the total non-labour share is unchanged. In these cases it is a matter of partitioning the gross operating surplus between the return to produced capital and the return to ecosystem assets. This is akin to the measurement of resource rent as applied in standard natural resource accounting and also to the valuation of ecosystem services via production function methods (Freeman *et al.*, 2014). However, for other ecosystem services a range of non-market valuation techniques will likely need to be applied as introduced in the SEEA Ecosystem Accounting (Chapter 9).

Beyond these ecosystem measurement challenges, a much more detailed mathematical representation of the Ecosystem MFP model is needed building on the logic presented in equation (7). In particular, it will be necessary to take the ecosystem accounting concepts and blend them with the standard capital and growth accounting theory and related index number approaches. An important aspect in this work will be understanding the alignment between ecosystem accounting and the production and consumption theory that underpins growth accounting. It is likely that research in this area will have related benefits in the ongoing research to develop valuation techniques for ecosystem services that are required for national accounting uses. Steps in this direction are evident in the work of Fenichel *et al.* (forthcoming) but more research and discussion is needed.

Also, research is needed on the appropriate accounting for actions taken by economic units to restore or enhance ecosystems. These actions will involve incurring labour, capital and intermediate input costs. But at present there is no additional output recorded in the national accounts and the connections to changes in the future flows of ecosystem services have not been well developed. A potential approach is to consider these costs as investments and, following standard national accounts practice, this would lead to increases in produced capital albeit that these investments are embodied in ecosystem assets. Appropriately disentangling the produced and natural capital elements and accounting appropriately for renewable assets is an important area for investigation.

In relation to implementation there are many areas of potential work. The implementation of ecosystem accounting is progressing and there are a wide range of landscape, national and regional projects underway but a single database containing the relevant inputs for calculation of the Ecosystem MFP measure has not been established. Experience to date suggests that progress on ecosystem accounting will generally involve bringing together a wide range of existing data. There would appear to be great potential to examine data that currently underpins the variety of environmental-economic models that have been developed that incorporate information on physical and ecological flows in conjunction with economic data. Integrating these data within an accounting framework will be an important step.

The most challenging area of measurement is likely to be the valuation of ecosystem services such that relevant cost shares within the accounting framework can be determined. Given that ecosystem services are not exchanged on markets, it will be important to advance the testing and implementation of appropriate non-market valuation techniques. One option that has emerged in the research for this article is the use of Malmquist indexes and distance functions which have been considered in EAMFP measurement but not, to the authors knowledge, applied in the context of valuing ecosystem services.

Overall, while these are challenging research tasks, the broadening of the MFP framework to incorporate environmental adjustments using ecosystem accounting provides an excellent platform for undertaking an integrated research program that can utilize findings from many different areas of work.

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