Computable General Equilibrium models with Natural Capital

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Authors: David Comerford*

*Corresponding author: david.comerford@strath.ac.uk

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Executive summary

This discussion paper is a report into mainstreaming natural capital and ecosystem services into economy-wide models.

Natural capital is the stock of natural resources or assets, which provide a wide range of goods and services, often called ecosystem services. Analogously to physical capital, ecosystem services can be conceived of as the dividend or interest rate flow that natural capital yields, while the natural capital value is the value of the stock of the asset. Like physical, human or social capital, it is possible to invest in natural capital, and to see natural capital depleted or depreciated if it is overused without investment.

Computable General Equilibrium (CGE) models are large scale models of the economy, with multiple productive sectors and potentially multiple household types (hence computable as simulations must be analysed numerically, rather than proving properties of the model analytically), in which budget constraints are satisfied and all markets clear (hence general equilibrium). Typically the productive sectors in CGE models combine labour and capital with other intermediate inputs in order to make their output, which is demanded by industry as intermediate inputs, and by final consumers.

The impact of changes in natural capital on economic performance, the impact of economic changes on the use or level of natural capital, and the feedbacks between these, are poorly understood. To understand these, we need to make the link between natural capital and the whole economy in a model, which is not yet standard practice. Much of the work to date in this area has been to incorporate natural capital and ecosystem services within a simple Input-Output (IO) system (see Anger et al (2014) and Moran (2017)). However, in IO systems, prices are fixed and changes in production follow any changes in demand in a mechanical way that is derived by looking at existing supply chains. We argue that there is value (such as more complete internal consistency, and the ability to analyse price based policy instruments) in incorporating natural capital and ecosystem services in CGE models rather than simply using an IO framework. While it is perhaps conceptually straightforward to extend the CGE modelling framework to natural capital stocks and ecosystem flows (e.g. productive sectors make use of natural capital stocks and ecosystem service flows in production, and consumers demand some provision of natural capital stocks and ecosystem service in consumption) there are significant practical challenges.

This paper discusses the information availability on natural capital stocks and ecosystem service flows, and how this information might be incorporated into CGE models in practice.

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National Accounts and Natural Capital

Existing economic accounts record the market values of transactions in the economy. The total sales of goods to final consumers is GDP, while the total sales of all goods to both final consumers and to other firms who use these goods as intermediate goods in their own production processes, is Gross Output. A partial account, detailing the production side, is produced as Input-Output tables (as discussed in Comerford, 2017). Input-Output tables can be complemented with other data to ensure that budget constraints for all economic actors are satisfied, in order to create a full "Social Accounting Matrix" (SAM). A SAM is the database that is used to calibrate a CGE model, in which scenarios that differ from the static IO data can be analysed. This is the standard operation of a CGE model and its data sources.

In reality, production processes also feature natural resources. These may produce final goods which are not measured in conventional GDP (and for which there is no market transaction) e.g. GDP should perhaps be boosted by the free goods of nature which are enjoyed in recreation, or reduced to account for the costs of carbon emissions. Including these missing final goods and costs means that an Environmentally augmented CGE models would naturally then produce estimates of so-called Green GDP (Hartwick, 1990) and/or Genuine Savings (Hanley et al, 2015), which are two attempts in the literature which adjust standard metrics of economic performance for sustainability.

Production processes which feature natural resources may, alternatively, best be modelled by creating new sectors which supply natural resources to existing sectors – making profits themselves while reducing the profits of the existing sectors (this does not imply any changes in the ownership of any profit streams) – which implies new intermediate goods are added to the national accounts (for which there is no market transaction) and so Gross Outputs would differ from published IO tables.

An environmentally extended SAM can be constructed on this basis to calibrate an environmentally extended CGE model. Such a model can then be used to generate scenarios for analysis in which: changes in natural capital have an impact upon economic performance; policy and/or economic activity have an impact upon the use or level of natural capital; and which shows the feedbacks between these.

Data availability for Natural Capital stocks and Ecosystem Service flows

The primary data source that we can draw upon is ONS (2016) who produce Natural Capital accounts for the UK covering some natural capital stocks and ecosystem service flows. Other data sources include: the World Bank's Wealth Accounting and the Valuation of Ecosystem Services (WAVES)[1]; and the System of Environmental-Economic Accounting (SEEA) Experimental Ecosystem Accounting (EEA) being developed by The United Nations Statistical Division (UNSD), the United Nations Environment Programme (UNEP) TEEB Office, and the Secretariat of the Convention on Biological

[1] See https://www.wavespartnership.org/en

Diversity[2]. In furthering this research, we hope to also be able to draw upon new work being produced under the Scottish Government's Rural Affairs, Food and the Environment, Strategic Research Programme, Theme 1: Natural Assets[3].

ONS (2016) provides estimates of the value of various ecosystem service flows for the UK, and calculates the value of the natural capital stock as the net present value of these flows projected into the future. This framework is appropriate for considering the value of an ecosystem service flow that is provided by some putative "environment" sector or institution. For example, ONS (2016) reports that "16% of the profits from agricultural production can be attributed to services provided by the UK's natural assets". One approach then could be to augment the expenditure of the agricultural sector to include payments to the environment sector (equal to 16% of gross operating surplus), thus reducing agricultural sector profits. The environment sector would have to then appear as its own sector in the Input-Output table or SAM, where it would sell its output to agriculture and make corresponding profits of its own (as discussed in Comerford, 2017).

Such a framework makes sense and can form a basis for the creation of a Natural Capital augmented CGE model. Note however that such a framework does not necessarily correspond to what may be our common sense notions of the value of the natural environment. In particular, the value of the ecosystem service flow is determined by the market value of the products produced with these services. This means that an increase in the price of a good, say agricultural produce, is interpreted as an increase in the value of natural capital – without there being any implication of environmental improvement. This is not necessarily a conceptual problem, but it may be a problem in communicating results.

ONS (2016) has valuations for the following ecosystem service flows, which are used in the production of traded goods and services: oil and gas; coal and peat; minerals; timber; water; agricultural biomass; fish; hydro power; wind power; and recreational services[4]. It also has valuations for air filtration and pollution removal, and carbon sequestration, which are currently "free goods", the inclusion of which will be additive to GDP. It describes the methodologies used to value these ecosystem services, which provides a basis for allocating these to the Scottish Input-Output tables and SAM. These could be allocated based on sectoral shares, land area shares, population shares, etc. as appropriate to the relevant ecosystem service flow.

Note also that the carbon sequestration ecosystem service flow is another case where communication issues could be problematic. Consider a mature forest or peatland that stores a large quantity of carbon, but in which current sequestration rates are zero. In this framework, the value of the carbon sequestration services provided is zero, and hence the value of the natural capital - as the net present value of these flows projected into the future - is also zero – despite its stores of carbon (of course if these were released then carbon emissions should attract a negative ecosystem service flow). Any model constructed which includes carbon sequestration should therefore also include carbon emissions on the same basis i.e. the social cost of carbon times total emissions will represent

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[2] See https://unstats.un.org/UNSD/envaccounting/eea_project/default.asp

[3] See http://www.gov.scot/Topics/Research/About/EBAR/StrategicResearch/strategicresearch2016-21/srp2016-21/naturalassets

[4] The value of Recreation Services are estimated using expenditures on admission, parking, and transport, and so are already captured in GDP.

a negative ecosystem service flow that will lower the GDP of the augmented Input-Output, SAM, or CGE system. Carbon emissions are available at sectoral level for Scotland from Scottish Government (2016).

Adding Natural Capital to CGE models

On the production side, it is useful to start with other attempts to expand CGE modelling beyond the use of capital, labour and intermediate inputs. Lecca et al (2011) discusses how energy should enter the production function, a discussion that extends naturally to ecosystem services and natural capital. The production functions typically used in CGE modelling are of the Constant Elasticity of Substitution (CES) family[5]. When output, Y, is produced using a simple combination of labour, L, and capital, K, the basic CES production function is given by:

$$Y = \left(\alpha K^{\frac{\sigma-1}{\sigma}} + \beta L^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \quad (1)$$

where α and β are the shares that must sum to 1 for a constant returns to scale production function, and σ is the elasticity of substitution between the factors. This can be extended to more inputs, say natural resources, R, but if this is done as in equation (2), then we are saying that the elasticity of substitution is the same, σ, between any two of these inputs.

$$Y = \left(\alpha K^{\frac{\sigma-1}{\sigma}} + \beta L^{\frac{\sigma-1}{\sigma}} + \delta R^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \quad (2)$$

The alternative is to nest the production function based on the elasticity of substitution between the various inputs. Suppose the elasticity between labour and capital was estimated at σ, but that the elasticity of substitution between this capital-labour composite and natural resources was estimated at ν. This would suggest a nested structure of the form of equation (3).

$$[K\ \ ] = \left(\alpha K^{\frac{\sigma-1}{\sigma}} + \beta L^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

$$Y = \left(\gamma [KL]^{\frac{\nu-1}{\nu}} + \delta R^{\frac{\nu-1}{\nu}}\right)^{\frac{\nu}{\nu-1}} \quad (3)$$

Alternatively the estimated elasticities could be best matched by nesting a natural resources-capital composite below the contribution of labour, or by nesting a natural resources-labour composite below the contribution of capital. The point Lecca et al (2011) make is to show that this nesting structure matters quantitatively, and that the implications of the modelling choices made should be tested.

These modelling choices relate to the concepts of Weak and Strong Sustainability in the environmental economics literature. Weak Sustainability is the idea that other capital can substitute

[5] CES includes Leontief, Cobb-Douglas, and linear perfect substitution as special cases for $\sigma = 0$, $\sigma = 1$, and $\sigma \to \infty$, respectively

for natural capital (see Hartwick, 1977), while Strong Sustainability has natural capital and other factors of production as complements. A value for the elasticity of substitution, between natural resources and other factors, of between zero and one, means that natural resources and other factors are complementary. In this case a scarcity of natural resources (low quantity used) implies that their value in production (price times quantity used) approaches the total value of the output. This is because with an elasticity of substitution less than one, natural resources are an essential input to production – we are in the realm of Strong Sustainability – and if the quantity input falls, then the price (marginal product) rises to such an extent that total expenditure on natural resources rises. In the Weak Sustainability case in contrast, with an elasticity of substitution greater than one, other inputs can be used as substitutes for natural resources. In this case, the use of a low quantity, though still associated with a rise in price (marginal product) implies that total expenditure on natural resources falls.

Such production functions can be conceptualised in an engineering framework: a given combination of inputs are combined to create outputs. But since marginal product theory is also used to determine prices and the distribution of the income that arises from production, we must also consider the ownership of natural capital stocks and ecosystem service flows. This may mean creating notional sectors in the economy that are paid rent for their provision of ecosystem services. These payments may cycle entirely within individual firms if, say, these firms are also landowners. This is similar to the "Imputed rent" that appears in IO tables as homeowners' consumption of housing services, in which the payment for these services is almost entirely profit, the entitlement to which is owned by these same homeowners (see ONS (2016b)).

So long as we are considering the production of the same final goods (e.g. augmenting agricultural production to include payments for the use of agricultural biomass ecosystem service flow as described in previous section), a Natural Capital augmented CGE model output for GDP should match published GDP figures. However, if there is no market transaction for the rent of natural capital stocks or for the purchase of ecosystem service flows, then the measures of Gross Output produced by a Natural Capital augmented CGE model will not match published figures for Gross Output, which exclude the "hidden" payments for these goods – "hidden", since no money changes hands. If we are augmenting the final goods considered (e.g. reducing (increasing) GDP by the social cost of carbon for each unit of carbon emitted (sequestered)), then the measure of GDP produced by a Natural Capital augmented CGE model will also be altered. If we are altering the suite of final goods in a GDP-type measure, then depending upon the final goods considered, then it could perhaps be benchmarked against estimates of Green GDP (Hartwick, 1990). Model output will also include estimates of Genuine Savings (Hanley, 2015) which can, depending upon the consistency of natural capital stocks in the model with external data, be benchmarked against this data[6].

[6] See e.g. http://data.worldbank.org/indicator/NY.ADJ.SVNG.GN.ZS?view=chart for World Bank data on what it calls "adjusted net savings".

As well as appearing on the production side, natural capital and ecosystem services may also appear on the demand side of the economy. In CGE models, consumers' utility is also typically represented in CES form, which means that demand for any particular good, i, is given by:

$$E_{i,t} = E_t \delta_i^{\rho} \left(\frac{P_t}{p_{i,t}}\right)^{\rho-1} \tag{4}$$

where $Exp_{i,t}$ is the expenditure on good i in time period t, Exp_t is the overall expenditure on consumption goods in time period t (related to other periods through an intertemporal Euler Equation), δ_i is the share in demand on good i, ρ is the elasticity of substitution across goods in the utility function, $p_{i,t}$ is the price of good i in time period t, and P_t is the overall price level faced by consumers in time period t.

To the extent that ecosystem services and natural capital are goods that are priced in the economy[7], they can be incorporated into this setup. Recreation is an example. To the extent that natural capital (e.g. biodiversity) adds to the quality of the recreation offered by a facility (e.g. a park), and to the extent that this facility charges admission, this is a straightforward concept to incorporate within the utility function and hence within consumer demand. (Though this is likely not to be a straightforward quantitative exercise.) The value of recreation in the case of a non-priced admission is more problematic. Many ecosystem services are not so straightforward: many national parks and wildland sites do not charge admission and can be enjoyed for free (estimates are then typically done using travel cost)[8].

Another example of an ecosystem service which is demanded and paid for, but which is problematic in this context, is the flood prevention services provided by forest cover. Perhaps this can be inferred from house price differentials across locations, combined with insurance premiums for those in locations which do face high flood risks, but once the ecosystem service of flood prevention is being provided in a region, there is no payment made for that service[9].

A further example which impinges upon both the production and consumption sides of the economy is all those ecosystem services that promote health. For example, the pollution removal services provided by urban trees, and the recreation opportunities provided by biodiverse amenity spaces

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[7] One response to this point may be that a large part of the point of including ecosystem services and natural capital goods in a model is that they are largely not priced in the economy. This is true, and we capture this for intermediate goods provided by the environment on the production side by introducing notional payments for these goods. We can also deal with this for final goods on the investment side e.g. carbon emissions are a cost because they damage the environment which will damage future productive capacity. However, it is not so straightforward to deal with this for final goods on the consumption side (using e.g. stated preference, Willingness-To-Pay results) within a general equilibrium model because budget constraints must all be satisfied and marginal utilities across all expenditure categories must all be equalised. Demand for a free good is incompatible with this modelling framework (if it's free then an optimising agent would demand it in infinite quantity) and alternative frameworks, like the Satisficing of Simon (1956) may be more appropriate.

[8] To include the value of recreation estimated through travel expenditures, it would be necessary to lower consumer demand for fuel and transport, add consumer demand for such recreation, and relabel consumer expenditures on transport as intermediate goods in the recreation supply sector. This is possible, and would not change GDP i.e. consumers here are paying for the value of recreation already through their transport purchases.

[9] Though payments for Flood Risk Management (e.g. an urban catchment paying a rural location to allow flood waters) will enter GDP.

and by beautiful landscapes, may promote health outcomes in the population. Clearly people value their own health outcomes and so this is a consumption good (albeit one which suffers from the same valuation difficulties, and difficulties in incorporation within a general equilibrium model which satisfies demand optimisation under a budget constraint). However, a healthy population is also a more productive population with a lower rate of inactivity, and higher human capital. It may therefore be ultimately desirable[10] to incorporate health promoting ecosystem services into an economy wide model in order to satisfy the basic objective of improving the understanding of "the impact of changes in natural capital on the conventionally measured economic performance, the impact of economic changes on the natural capital, and the feedbacks between these".

Conclusion

In this discussion note we have identified some principles for combining natural capital and ecosystem service flows with computable general equilibrium models, and discussed some of the practicalities. We now proceed with computational edits to incorporate these principles, and will be guided by data access, and discussions with colleagues and project stakeholders on the precise specification to be included and coded.

It is likely that in the first instance, in addition to incorporating carbon accounting flows, we will devote most effort to adding certain natural capital stocks and ecosystem service flows to the production side of the economy, in the production of goods which are within the definition of published GDP.

1.4.2ciii D4 (due 2017-18) will use a CGE model augmented with carbon accounting flows to go beyond a simple Input-Output analysis in analysing "The economic impact of healthy eating as part of climate change policy" (1.4.2ciii D3, also due 2017-18, will cover the simple IO analysis). Incorporating carbon accounting flows into a CGE model will allow us to consider the impact of price or productivity changes. This allows us to compare the whole economic impact of the dietary shift as being the equilibrium response to (1) tax policy; versus (2) a shift in consumer preferences; or (3) the adoption of new production practices that lower both productivity and emissions per unit produced.

The incorporation of further natural capital stocks and ecosystem service flows into CGE models, for example agricultural biomass, will allow us to explore further questions of policy relevance. For example payment schemes which spend the budget previously spent under the EU's Common Agricultural Policy can be targeted at environmental improvement and the provision of ecosystem services. Such policies could be looked at in a comprehensive model that jointly features agricultural profitability, ecosystem services, and agriculture's links into the wider economy. Analysis in such a framework could be invaluable when considering analysis associated with Brexit and the environment.

[10] Though data availability versus data requirements mean that this is not something that will feature in the modelling initially.

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