# Incorporating Natural Capital into A Computable General Equilibrium Model for Scotland

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## Abstract:

**Research Question:** Natural capital encompasses those assets which are provided by nature and which are valued by economic actors. As such, there is a clear analogy between natural and other assets, such as labour and capital, which are routinely included in models of national economies. However, the valuation of natural assets, to the extent that they are included in such models, is typically wrapped up in physical capital along with land values or not valued at all. This could be simply a measurement problem – natural capital might be difficult to appropriately disaggregate from other capital – or because they provide non-market goods which are not included within traditional measures of economic output. The purpose of this paper is to set out – both conceptually and practically – how natural capital can be added to a computable general equilibrium model. **Method/Data:** We focus on the conceptual differences that should reflect such an extension and we explore the empirical implementation of our approach through the addition of an agriculture biomass ecosystem services flow to a CGE model of the Scottish economy. This paper specifies the CGE model development as well as including some illustrative simulations. **Novelty:** The natural capital extended CGE model allows us to track the impact of disturbances, including policy changes, on the economy and environment and therefore on sustainable development. In the longer term comprehensive coverage of natural capital stocks and ecosystem services will allow us to track the impact of disturbances, including policy interventions, on Green GDP and Genuine Savings, as well as on aggregate and sectoral economic activity.

## 1. Introduction

Environmental policy is increasingly prominent, especially given the realities of climate change, but not at the expense of economic well-being. Many countries, in effect, have a policy of "Sustainable economic growth", which seeks to take into account the environmental impacts of economic development. Given environmental inputs to production and environmental goods that we all enjoy, it is impossible to assess whether the economy is sustainable if we do not monitor the state of the environment. To undertake policy analysis given this, we need to link macroeconomic models capable of evaluating impacts of policy interventions and scenarios with natural capital and ecosystem services within a single coherent framework.

Natural capital is the stock of natural resources or assets, which provide a wide range of goods and services, often called ecosystem services (UK NEA, 2011). 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.

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 and not typically modelled within existing applied economic models. To improve our understanding of these relationships, we seek to explicitly link natural capital to the wider economy within a system-wide, economy-environment model.

Much of the work to date in this area has involved incorporating natural capital and ecosystem services within a simple Input-Output (IO) system (see Anger et al, 2014). However, in IO systems, prices are fixed and changes in production follow any changes in demand in a mechanical way that reflects existing supply chains.

We argue that there is likely to be considerable value-added, in terms of contributions to both the academic literature and to policy analysis, in incorporating natural capital and ecosystem services in Computable General Equilibrium (CGE) models.

The paper is structured as follows. Section 2 discusses how, in principle, natural assets may be incorporated within general equilibrium models, and the analogues between natural assets (or natural capital) and any other asset. Section 3 then outlines the data and methodology used to extend the

AMOS (A Macro-Micro Model for Scotland) CGE model, with the simulations and results detailed in Section 4. Section 5 concludes.

## 2. Adding Natural Capital to General Equilibrium macroeconomic models

Computable general equilibrium models are typically large scale economic models calibrated to one or more national economies, in which all factors are paid their marginal product, firms maximise profits, consumers maximise utility, budget constraints are satisfied, and all markets clear simultaneously (subject to any explicitly modelled frictions e.g. labour market frictions which allow equilibrium unemployment). Such models are multi-sectoral in nature, with many different final goods produced (whose total value gives Gross Domestic Product (GDP), on an expenditure basis) and a complicated production structure which makes use of many intermediate goods. Typically, there are two factors of production: labour and capital, payments to which also total to GDP (on an income basis).

Such models therefore typically fail to accommodate key features that are likely to be crucial to an informed analysis of the environment. In particular, production processes also feature the use of natural assets (or natural capital) or some notion of "inputs" from nature (in the form of "ecosystems service flows") to generate outputs. (We distinguish different forms of ecosystem services below.) This use of natural inputs in production is analogous to the use of physical capital stocks and intermediate goods in production. Additionally, natural capital and/or ecosystem service flows may be enjoyed by consumers, analogously to how they enjoy consumer goods. It is clear therefore that we might usefully extend economic models, by analogy with how assets and goods are already treated within them, to encompass natural capital stocks and ecosystem service flows.

Natural capital is usually divided into three types (see Millennium Ecosystem Assessment, 2005) according to what ecosystem services these assets provide: provisioning services are goods or services, usually already included in economic accounts, and provided by nature – the water environment for fisheries production is a good example; supporting and regulating services are maintenance services that nature provides for free, e.g. the action of a landscape can provide clean water that a water company takes advantage of, and which would be costly to replicate without the natural asset; and cultural services are goods valued by people for their existence, and which are typically not traded – a beautiful landscape is a good example.

From an economic modelling view however, natural capital broadly produces either (final) goods which are not already counted in economic output, or it produces inputs to production of (either intermediate or final) goods that are already counted in economic output.

In this second case the production function of the sector which uses the natural input has to be altered beyond the use of physical capital, labour and intermediate inputs. For example, Lecca et al (2011) discuss how energy should enter the production function, a discussion that extends naturally to ecosystem services and natural capital. CES production functions are widely used in CGE modelling. When output, Y, is produced using a simple combination of labour, L, and capital, K, the basic CES production function is given by:

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

where $\alpha$ and $\beta$ are the shares that must sum to 1 for a constant returns to scale production function, and $\sigma$ is the elasticity of substitution between the factors. This can be extended to more inputs, say ecosystem service flows, F, but if this is done as in equation (3), then we are assuming that the elasticity of substitution is the same, $\sigma$, between any two of these inputs.

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

This is the methodology used for this paper and now  and $\beta$ and $\delta$ sum to 1 for a constant returns to scale production function[1].

## 3. Methodology

In this paper we focus on exploring the introduction of the agricultural biomass ecosystem service, which we have data on from ONS (2016a), into a CGE model. The purpose of this paper is provide details of the conceptual problem might be resolved in applied CGE models and to illustrate this methodology with two illustrative cases.

### 3.1 Data

ONS (2016a) reports that the value of ("provisioning services") ecosystem service flows provided to agricultural production in the UK in 2013-14 was1.5bn. This figure can be apportioned in some way to Scotland (using a population share to reflect Scotland's larger land per capita, but poorer agricultural land quality). The following table is from ONS (2016a) UK natural capital ecosystem accounts for freshwater, farmland and woodland.

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[1] An alternative is to nest the production function based on the elasticity of substitution between the various inputs

**Table 13: UK farmland annual monetary value by service, 2007 to 2015**

| | | | | | | | | | | £ million |
|---|---|---|---|---|---|---|---|---|---|---|
| Type of Service | Service | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
| Provisioning Services | Crops and grazed biomass | 235.0 | 1,555.1 | 0.0 | 1,300.3 | 1,079.2 | 1,160.5 | 1,763.1 | 1,330.1 | |

These figures are calculated on a *Resource Rent* basis. That is, agricultural profits (which can be observed in the UK IO tables) are deemed to be a fair return on capital invested in agricultural activities (for presumably the ONS have some estimate, despite this not being observed in IO tables). However, it seems that agricultural profits typically outstrip the fair return on the physical capital stock in agriculture, and the ONS attribute the balance of the profits, over the fair return to physical capital, to a return on environmental assets.

The values in the table above show large fluctuations in the value of this ecosystem service calculated in this manner. These fluctuations are largely caused by fluctuations in the price of agricultural output, which causes fluctuations in agricultural profits, which feed directly through to the value of the ecosystem service flow, since the fair return on physical capital will not fluctuate so much.

ONS (2016b) also provide associated natural capital stock values, equal to the discounted present value of future ecosystem service flows. Future ecosystem service flows are estimated as the average of the previous 5 flow values, assumed constant in into the future.

| Natural Capital Monetary Estimates - Asset Values, £ million, 2014 Prices, 2007 - 2014 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2006 (£m) | 2007 (£m) | 2008 (£m) | 2009 (£m) | 2010 (£m) | 2011 (£m) | 2012 (£m) | 2013 (£m) | 2014 (£m) |
| **Provisioning Services** | | | | | | | | | |
| Agriculture[1] | | 14,859.7 | 20,860.1 | 12,992.6 | 15,462.2 | 16,760.4 | 21,274.5 | 22,288.9 | 32,352.9 |

If we model these assets as perpetuities, and label as $\overline{[pF]}$ the annual flow value of ecosystem services (equal to the average flow value over the previous 5 years), $V$ as the asset value, then we have $r = \frac{\overline{[pF]}}{V}$ relating these two data series from the ONS. Doing this (starting in 2011 since that is first year for which we can calculate a 5 year average) produces a series of implied interest rates:

| 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|
| 4.9% | 4.8% | 4.7% | 4.1% |

The consistency of these implied interest rates is indicative of the fact that the asset values are less subject to the fluctuations produced by the calculation method for this ecosystem service. Given that when calibrating the CGE model, we assume the base year calibrated position of the economy is a steady state, it is appropriate to use the asset value series from the ONS for the value of this ecosystem service. Therefore the data series can be based on the equation $\overline{[pF]} = rV$ where $V$ is the natural

capital asset value based on ONS data, adjusted for Scotland's "share", and $r$ is the market interest rate in the CGE base year/calibration.

## 3.2 Creating an Environmental Sector in the CGE Model

The resulting input to production must be paid for i.e. the nominal value of the inputs to agriculture, $\overline{pF}$, are paid by the agriculture sector to the environment sector, reducing agriculture profits, and realising environmental profits (the owners of these two profit streams are the same agents however, so budget constraints are unaffected). This is straightforward.

What is perhaps not so straightforward is choosing how this environmental sector optimally supplies inputs to the agricultural sector based on the prices it sees and the physical characteristics of the good it is supplying.

We firstly need to make modelling decisions about how this natural capital stock responds to its exploitation in production. We imagine that natural inputs to agriculture can be over-used if production is too intensive, but that if allowed to regenerate, then they do so. By analogy with the depletion and accumulation processes usually assumed for renewable resources (and in particular for fisheries), we postulate a logistic process for the real stock of environmental inputs available, $S_t$:

$$S_{t+1} = S_t + gS_t \left(\frac{\bar{S}-S_t}{\bar{S}}\right) - F_t \tag{3}$$

where $F_t$ is the real quantity of inputs supplied to the agricultural sector, $g$ is the regeneration rate for this environmental asset, and $\bar{S}$ is the available stock that the system would tend towards in the absence of any use of this asset.

At time $t$, the environmental sector choses a sequence $F_s$, $s \geq t$, to maximise the present value of supplying ecosystem services, taking prices as given (this is consistent with there being a myriad of suppliers in this sector, none of which is big enough to influence the price of environmental inputs), $\Pi_t = \sum_{s=t}^{\infty} \beta_t(s)E_t[p_s]F_s$, where $\beta_t(s)$ is the discount factor that applies over the interval $(t, s \geq t)$, and $E_t[.]$ denotes expectations formed at time $t$.

It can be shown that the environmental sector follows a policy rule for deciding the real quantity to supply as a function of prices and the available stock:

$$F_t = S_t + gS_t \left(\frac{\bar{S}-S_t}{\bar{S}}\right) - \frac{\bar{S}}{2g}\left(1 + g - \frac{p_t}{\beta_t E_t[p_{t+1}]}\right) \tag{4}$$

Which has steady state values for the stocks and flows:

$$S^* = \frac{\bar{S}}{2g}\left(1 + g - \frac{1}{\beta^*}\right) \tag{5}$$

$$F^* = gS^*(\frac{\bar{s}-S^*}{\bar{s}}) \tag{6}$$

This supply is then incorporated into the extended production function (Equation (1)) for the agriculture sector.

## 4. Simulations and results

The previous sections have detailed the conceptual framework of the ecosystem-extended multisectoral[2] CGE model. In this section we show the results of two illustrative simulations generated using the extended model.  The first of these simulations is a demand-side disturbance – a permanent 10% increase rest of UK (rUK) agriculture exports – and the other a supply-side change – a permanent 10% productivity increase in the agriculture biomass.  These shocks are chosen so as to illustrate the impact of conventional economic disturbances (case 1) with and without the extended model, and to illustrate how the model can be used to produce economic impacts of changes in the availability and usefulness of the agricultural resource.

Firstly, we compare the overall results of a 10% increase in rUK agriculture exports increase generated using the extended model with the results for the same disturbance using the base AMOS model (labour & capital).

Table 1. Long run results of 10% rUK agriculture export increase

|  | Base model | Agricultural biomass model |
|---|---|---|
| GDP | 0.036 | 0.028 |
| Employment | 0.025 | 0.019 |
| Labour supply | 0.025 | 0.019 |
| Investment | 0.052 | 0.040 |
| Capital Stock | 0.052 | 0.040 |
| Household consumption | 0.017 | 0.017 |
| Exports | 0.078 | 0.071 |

When extending the AMOS[3] framework to incorporate agricultural biomass, with an increase in agriculture exports, we report smaller overall economic impacts when compared with the standard model - which is to be expected. In the extended model, capital in the agriculture sector has been separated into both physical and natural capital (biomass). With the introduction of the demand

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[2] Appendix A list the sectors in the model.
[3] A Macro-Mirco model for Scotland (AMOS) is a CGE framework which has been used for a wide range of applications.(Harrigan et al (1991)).

disturbance the physical capital accumulates in the same manner as the base modelhowever, natural capital accumulates according to Equation (3). This natural capital accumulation is limited by the biomass regeneration rate (g) thus natural capital acts similarly to a fixed factor, reducing economic impacts. The CGE framework also measures the response of several variables due to a disturbance, in Figure 1 and 2 we focus on the response of the natural capital price, flow and stock with a 10% increase in agriculture rUK exports.

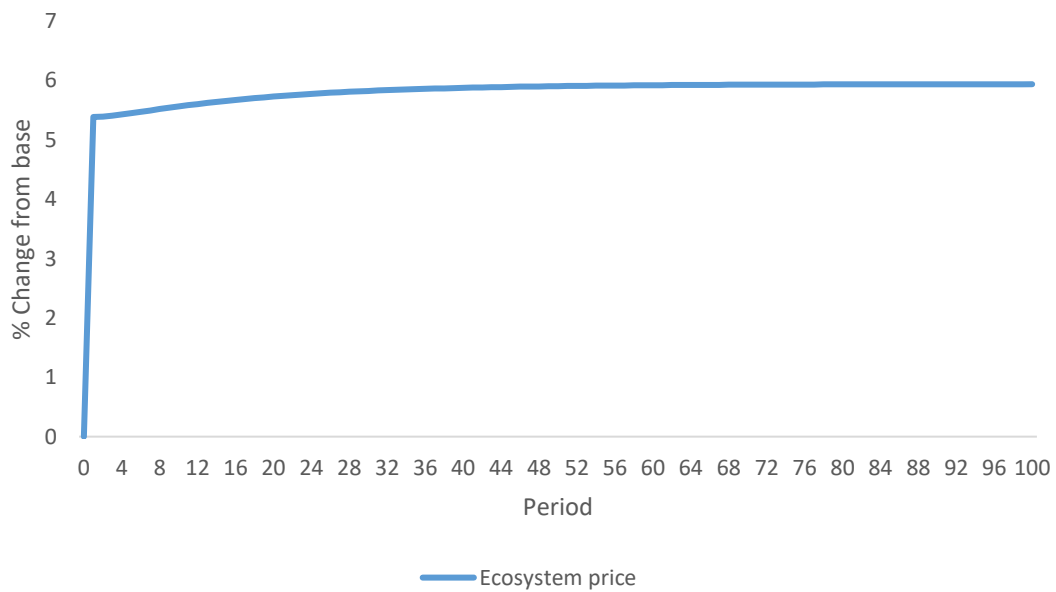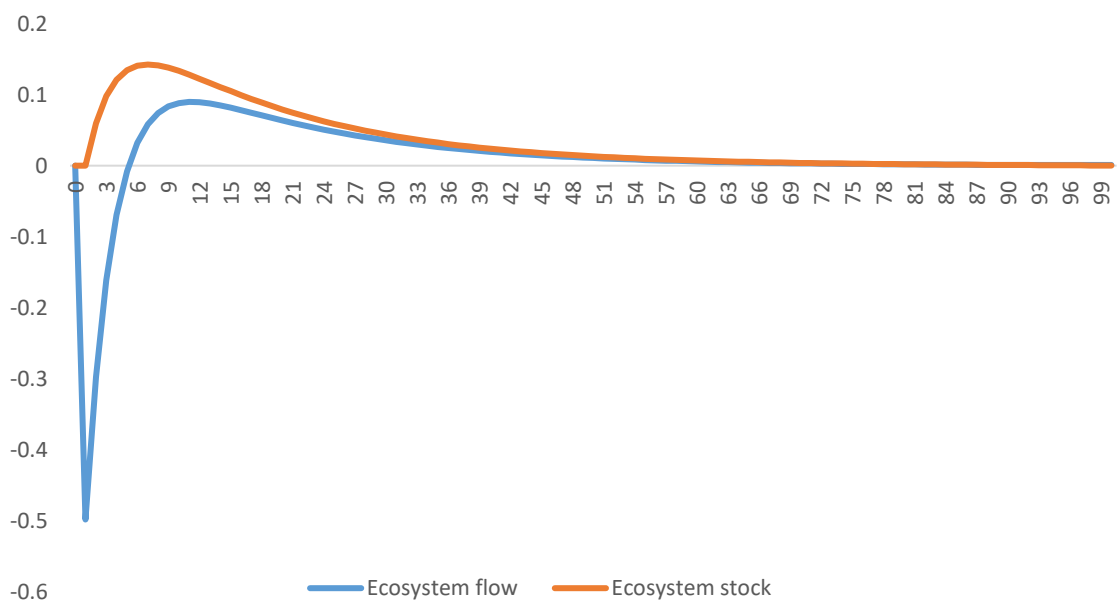Figure 1. Natural Capital price with 10% increase in rUK agriculture exports



Figure 2. Natural Capital flow and stock with 10% increase in productivity

In Figure 1 we find that in the first period the price of natural capital increases by 5.39%, induced by the increase in demand for agriculture good and services (exports). After this first period the price of the natural capital continues to gradually rise, as the economy adjusts to the increased exports, until equilibrium is reached and the price of ecosystems remains 5.94% above the initial equilibrium. This change in price, along with the stock and regeneration rate, impacts the flow (use) of the natural capital. Even though there is an increase in agriculture demand there is actually a fall in ecosystems use in the first period, caused by the substitution of other factors. As identified previously, the extended model allows for substitution between natural capital, physical capital and labour and in this simulation the prices of physical capital and labour do not rise as much as natural capital thus there is substitution away from natural capital.

After this negative peak at period 1 there is a gradual increase in the flow of natural capital, through this is still below the initial equilibrium value. Equation (4) illustrates that natural capital flow is dependent on current stock as well as prices and as the flow is below the equilibrium point at period 1, the stock at period 2 is slightly greater, allowing for more natural capital to be used. Natural capital flow is below equilibrium value until period 6 with the stock constantly increasing, after period 6 (with the large increase in stock) the natural capital flow becomes more than equilibrium with peak use at period 12. After period 12 both the flow and stock reduces such that equilibrium is reached.

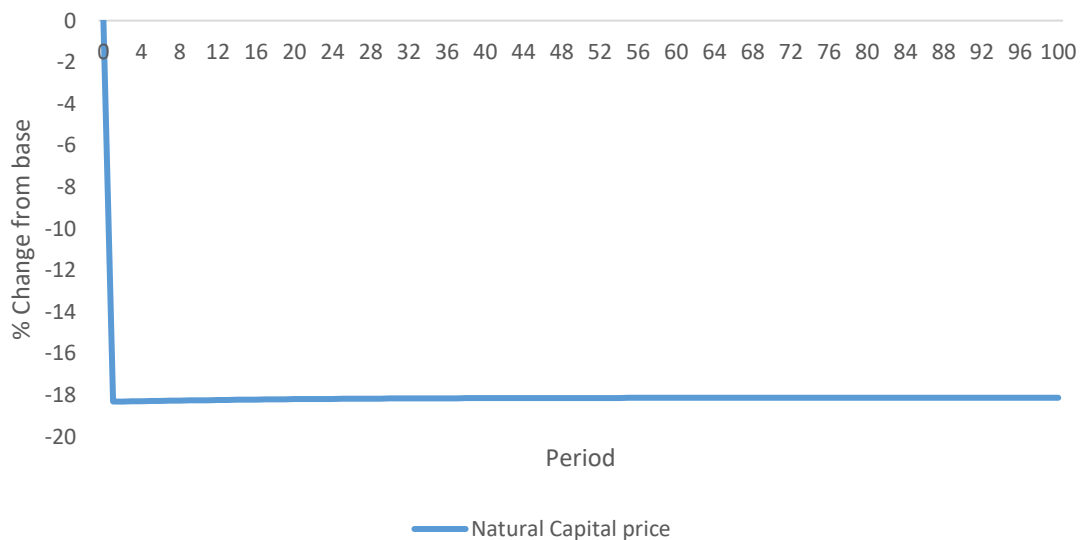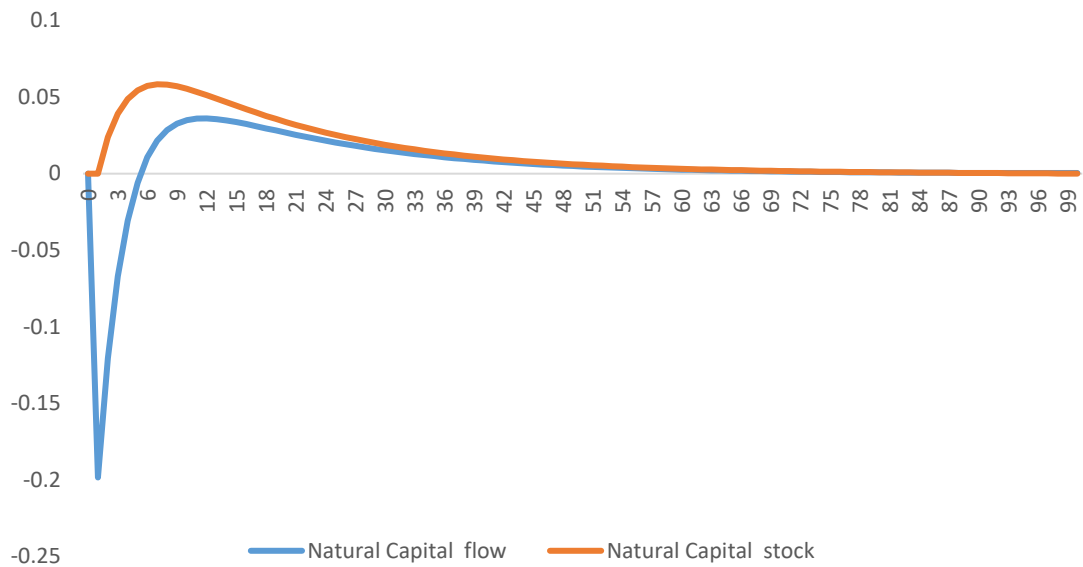Figure 3. Natural Capital price with 10% increase in productivity



Figure 4. Natural Capital flow and stock with 10% increase in productivity

In contrast with the previous simulation, an increase in natural capital productivity yields a decrease in the price simultaneously with a reduction in flow in period one. As natural capital becomes more productive less natural inputs are needed for the same level of output decreasing the value of the natural capital. After period 1 however we find a similar pattern to that of the demand-side simulation. There is a gradual increase in the use natural capital flow, but still below the equilibrium value, increasing to a peak above the initial value. Again, from this peak both the natural capital flow and stock reduces gradually until they reach equilibrium.

## 5. Conclusions

This paper has explored the challenges involved in integrating natural capital and ecosystem services within computable general equilibrium models. The general approach has been illustrated through the specific example of agricultural biomass ecosystem service flows as an input into agricultural production, a focus that precludes any impact on value-added that would, for example, arise through the incorporation of ecosystem flows that are currently not valued within measures of GDP. Issues of appropriate model specification are addressed through comparison with the current treatment of the agricultural sector within a computable general equilibrium model, which does not separately identify natural capital stocks and their associated service flows. The data on natural capital stocks and ecosystem flows are discussed and are used, together with key parameter values, to calibrate an illustrative partial equilibrium model of the agricultural sector which augments the AMOS specification of that sector to incorporate a natural capital stock and its associated flow of ecosystem services. Two illustrative simulations (a demand-side and supply-side) were run using the natural capital extended model and the results appear plausible.

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# Appendix A – Sectors within model

| Model Code | Sector |
|---|---|
| PRY | Primary energy |
| ARG | Agriculture |
| MET | Red meat |
| MET | Meat processing |
| FDS | Food and drink |
| MAN | Manufacturing |
| ELE | Electricity |
| GAS | Gas |
| TRP | Transport |
| WHR | Warehouse and retail |
| PUS | Public services |
| PRS | Private services |