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Three Essays on Policy Modelling: An Inter-Temporal Computable General Equilibrium approach

By

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Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Date:

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Abstract

The thesis contains three independent essays on policy modelling. In all three, a numerical dynamic general equilibrium framework is used to discuss methodological advances in regional economic modelling and to analyse specific policies for the economies of Sardinia, Scotland and the United Kingdom respectively.

In the first essay, I present a stylized regional intertemporal forward-looking model able to take into account regional economic features. Furthermore, I discuss some of the objections to myopic models, such as the presumed lack of capital adjustment and the differences in the long-run steady-state results between myopic and forward-looking models. I show that properly specified myopic and forward looking models produce identical results in the long run, in contrast to claims in some of the literature in this area.

In the second essay I investigate the impact of a balanced budget fiscal policy expansion. I take Scotland as an example where, recently, there has been extensive debate on greater fiscal autonomy. In response to a balanced budget fiscal expansion the model suggests the following results. First, an increase in current government purchases of goods and services has negative multiplier effects only if the elasticity of substitution between private and public consumption is high enough to reduce the marginal utility of private consumers. Second, public capital expenditure crowds in consumption and investment even with a high level of congestion. Third, crowding out effects might arise in the short-run if agents are myopic.

CGE modelling techniques have been widely used in the literature to examine the rebound effect in an economy wide context. However, most of the studies focus on economy-wide rebound from an energy efficiency improvement on the production side of the economy. In the third essay, I present simulation results for an improvement in energy efficiency in the household sector which is a clear example of a demand side shock where households take all prices as given and with limited supply side effects.

Chapter 1

Introduction

The Computable General Equilibrium (CGE) modelling framework I develop is a single-region dynamic model. It can be seen as an applied and more extensive version of the skeletal model presented in Abel and Blanchard (1983). Investment decisions follow a Tobin's q adjustment process, and are separated from savings decisions. The former reflect the intertemporal optimisation of firms and the latter are the outcome of intertemporal optimisation by households. Thus, the model shares some similarities with previous business cycle models, in so far as the forward looking dynamic structure is concerned. The main difference is in wage setting and migration. Following Layard *et al*. (1991; 2005) and McGregor *et al*. (1996) the model incorporates imperfect competition in the labour market and allows for unemployment and population updating through a net migration function.

In the traditional business cycle model, migration is absent and real wages are unrelated to the capacity of workers to restore their purchasing power and/or not associated with the capacity of the firm to use unemployment as a "discipline device". This means that unlike, the standard model, this approach does not allow for substitution between consumption and leisure where the representative consumer chooses the quantity of labour to supply according to a flexible nominal wage. Rather, the model constructed here contains a wage bargaining function sensitive to the movement of the unemployment rate, and labour supply may also change through population adjustment due to net migration flows.

The title of the first essay is "Myopic and Forward Looking Regional Computable General Equilibrium Models. How Do They Differ?". I present a stylized regional intertemporal forward-looking model able to take into account regional economic features, a topic that is not well developed in the literature. The main difference from standard applications is the role of savings and its implication for the balance of payments. Intertemporal forward looking models are usually calibrated on national data. However a slavish application of the characteristics of such models may be problematic in a regional context since regions may differ in significant respects from the country as a whole. It is argued that intertemporal consumers' optimization based on neoclassical or Fisherian intertemporal resource allocation is inappropriate to the region since endogenizing the path of savings involves a balance of payments constraint which is not binding on regions. Furthermore, I compare forward looking and myopic models. This is valuable because in the literature the intertemporal model has generally been compared to a simple static myopic one. That is to say, it has been compare to a model which lacks any capital adjustment rule. Contrary to previous exercises on this topic, I find that the only difference between the two models is in the transitional pathway. Here consumption and investment might diverge in the two models since agents with perfect foresight have rational expectations, whilst those with myopic foresight take decisions according to adaptive expectations without making any optimizing decisions concerning future profit and income.

In the second essay, I investigate the impact of a balanced budget fiscal policy expansion in a regional context. I take Scotland as an example where there has recently been extensive debate on greater fiscal autonomy. Given these developments it is particularly important to understand the probable effect of fiscal policy in regional economies that are endowed with tax varying powers. The Scottish experience represents one of the most interesting cases within the EU. The Scottish people are engaged in a lively, on-going debate on greater fiscal autonomy and independence, which is politically controversial, especially in respect of tax-varying powers.

In light of recent contributions to the literature the model has been extended to distinguish between government current and capital expenditure, allowing different treatments of government expenditure according to its nature and purpose. Current government expenditure is treated as a simple purchase of goods and services so that its effect is confined to the demand side of the economy, whilst capital expenditures are treated as public investment that contributes to the accumulation of the public capital stock, and consequently affects both the demand side and the supply side of the economy through its impact on productive capacity.

The model is also able to account for congestion effects. In order to take into account the degree of *non-publicness* of public goods, public capital stock and current government expenditure are adjusted following a simple model consistent with median voter demand studies (see Edwards, 1990 and Fisher and Turnovsky, 1998). The congestion model I use follows the traditional formulation of decreasing marginal congestion.

In response to a balanced budget fiscal expansion the model suggests that an increase in current government purchase of goods and services has negative multiplier effects only if the elasticity of substitution between private and public consumption is high enough to reduce the marginal utility of private consumers. Furthermore, public capital expenditure crowds in consumption and investment even with a high level of congestion. However, crowding out effects might arise in the short-run if agents are myopic.

It is widely accepted that a significant effect of an improvement in energy efficiency is a fall in the effective price of energy. This should partially offset the expected reduction in energy consumption resulting from an energy efficiency improvement. This phenomenon is known in the energy economic literature as the "rebound effect[1]". Most of the existing studies are set in the context of energy efficiency improvements on the production side of the economy. In the last essay, however, I focus on the economy-wide impacts of energy efficiency in the household sector,

[1] The rebound (or backfire) effect arise when the improvement in energy efficiency is partially (or totally) offset by an increase in energy consumption. The rebound effect (R) is generally defined as follow: $R = \left[1 + \frac{\dot{E}}{v\rho} \right]$; where $\dot{E}$ is the percentage change in total energy consumption, ρ is the value of energy efficiency improvement and v is the proportion of the initial energy use to which the efficiency improvements directly apply.

with particular attention to the conditions under which rebound (or “backfire”) effects may occur.

I have estimated the elasticity of substitution between energy and non-energy in household consumption. Two interesting findings can be observed from the simulation results. First, when we use the long-run elasticity to obtain both the short and long-run impacts, rebounds are lower in the long-run than the short-run. This is the case already identified in previous works using CGE models (Allan *et al*., 2006; Hanley *et al*., 2007, Turner, 2009) and in the partial equilibrium context (Allan *et al*., 2010). Second, when the short and the long-run impacts are obtained using the short and the long-run elasticities respectively, rebounds are lower in the short-run than the long run. This result is instead consistent with previous analytical works (Saunders, 2008; Wei, 2007 and 2010).

I also investigate how alternative assumptions about consumers’ time preferences affect the magnitude of both the household and economy-wide rebound effects. I contrast the conventional time-separable lifetime utility specifications with the case where preferences over consumption exhibit habit formation. In doing so, I use a simple specification of habit persistence, as in Boldrin *et al.* (2001), which distinguishes between internal and external habit formation (Abel, 1990).

The CGE models I develop represent a significant extension of the AMOS CGE modelling framework (Harrigan *et al*. 1991). The main difference between the original AMOS framework and the variants proposed here rests on the model’s dynamic structure and on agents’ expectations. I use a typical infinite horizon model with forward looking dynamic structure where thus consumers and producers possess perfect foresight. This contrasts with the model’s existing recursive dynamic structure. These new features make the CGE model closer to a conventional macroeconomic real business cycle models.

All the models contained in these essays are programmed in GAMS and are therefore coded independently from the original AMOS program. Since the myopic version of the model has been coded with the purpose of replicating the results of AMOS, these developments of the model structure can be regarded as a variant of AMOS. The related GAMS files, with documented running instructions, are available on request.

Chapter 2

Myopic and Forward Looking Regional Computable General Equilibrium Models. How Do They Differ?

JEL classification: C68; D58; D91; R10

Keywords: Myopic and Forward-looking Behaviour; Computable General Equilibrium Models; Regional Adjustment.

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1. Introduction

CGE models based on myopic expectations have been criticised by the supporters of forward-looking models because of the intertemporal inconsistency involved in assuming backward-looking expectations. The models solve complex optimization problems within periods in order to determine the best allocation of resources. However, between periods they remain myopic, with consumption, saving and investment decisions abstracting from future periods (Devarajan and Go, 1999). Some doubts also arise when the policy to be evaluated has intrinsic long-run effects such as trade liberalization policy. Go (1994), Devarajan and Go (1999), and Dissou (2002), argue that myopic models fail to capture dynamic policy gains and, consequently, produce both inaccurate and incorrect results. For example, Devarajan and Go (1999) demonstrate that the welfare gains of eliminating trade tariffs are greater in forward-looking models than in static models[2]. I argue in this paper that such differences are the result of the different adjustments incorporated into these models and not, in fact, the consequence of differences in their dynamic structure.

[2] Also see Dellink (2005) on environmental policy.

The theoretical structure of many intertemporal forward-looking CGE models is that described in Abel and Blanchard (1983). Such a model can be solved as a decentralized economy where consumption decisions are made by intertemporal optimizing households, and savings and investment decisions are separated. The sector financial balance equilibrium is maintained, either through adjusting foreign borrowing, the interest rate, or by means of fiscal policy that, in turn, affects the financial wealth of households. Firms' forward-looking behaviour influences their investment decisions which depend on the tax-adjusted Tobin's *q*. Furthermore, in their stylized form, such models usually make households fully liable for the financial needs of the system. Hence, household savings would cover not only the needs of domestic investment, but also, ultimately, trade and Government deficits. Accordingly, households have to save as much as is required to clear the financial sector which, in turn, implies the imposition of a balance of payments constraint.

In fact, forward-looking models are frequently calibrated on national data and their specification is nowadays becoming standardized. However, a slavish application of specifications that imply a zero balance of payments, and where the savings rate is obtained endogenously through sectoral financial balance equilibrium, may be inappropriate in a regional context since key aspects of the regional economy generally differ from those of national economy.

It is widely recognised that regions are more open than nations and that these economies do not have full macroeconomic power. Both monetary and fiscal policies are centralized and are under the control of national Government. Therefore target policies and some macroeconomic adjustment mechanisms whose incorporation are uncontroversial in a national model, cannot routinely be applied at the level of region[3]. Furthermore, regions, unlike nations, do not face a balance of payments constraint. We can identify at least two reasons for this. Firstly, balance of payments is not required as a policy target since regions usually belong to a common currency area and to a nationally integrated financial system. As a result, fiscal and monetary policies cannot be used to produce balance of payments adjustments through control

[3]Even though some nations are likely to behave as regions (European countries for example).

variables such as exchange rates, reserve assets and interest rates. Secondly, the subvention that regions receive from higher level authorities such as centralized Government and the EU, may cause some distortionary effects so that a rigorous theory of the composition of the balance of payments is not really a regional issue. As pointed out by McGregor *et al*. (1995), such subventions are key determinants of the trade deficit in the region.

The point is that forward-looking models impose a balance of payments equilibrium in order to maintain financial sector sustainability, but regions are not obliged to undergo any form of financial adjustment. For instance, if a region faces an unsustainable position in which a net foreign debt is accompanied by a persistent trade deficit, it is not required to adopt rigorous adjustment in order to produce a trade surplus to cover interest payments because there are no superior authority to impose it. A superior institution such as central Government, may reduce the subvention to reduce its level of debt and, in turn, the region's debt (that is unobservable). However, this is a process that happens outside of the region. It means that if any adjustment exists this is imposed exogenously, from outside the region, not as an endogenous mechanism. This also means that the Ricardian implication of the fiscal deficit usually embedded in consumers' optimal decisions might be unrealistic; typically regional Government cannot finance its expenditure by levying taxes or issuing bonds since regional policy is an exogenous variable that depends on the subvention received from outside the region.

In an infinitely-lived agents model with perfect foresight consumers (this imply rational expectation), the Ricardian equivalence is embedded in the consumer's optimal decision problem. So that, consumers react to an expansion in government expenditure taking into account of the expected future loss of a raise in taxes. This also means that in order to offset the tax burden consumers will reduce consumption neutralizing the positive effect of an increase in taxation.

A model where the Ricardian equivalence is incorporated in the consumer's optimal problem does not allow dealing properly with external shock that to some extent are typical of a regional economy. In fact, as I have mentioned earlier, a Region (that belong to a Nation) does not have fiscal policy power so, an increase in government expenditure does not require, any fiscal adjustment.

This has also implication for any exogenous shocks simulated in a CGE model. So, one of the purposes of the paper is to readapt the consumer's decision problem in a way that not necessarily consumers have to readjust their consumption to offset the burden of taxation, since the regional Government does not have any power to levy taxes.

Of course, given widespread movement towards greater devolution within the EU, more regions will be equipped with instruments to deal with the reduction in subventions, thereby introducing specific sustainable targets that might bring about a partial endogenous financial adjustment operating within the region. So, only when regions start to behave like countries belonging to a common currency area, e.g. the European countries, does the balance of payments begin to be a matter at the regional level, and any adjustment in internal and foreign assets ceases to be exogenously determined. This does not mean that the traditional approach to the balance of payments should be applied. In this case, also for these regions, interregional and international payments constraints should not necessarily be imposed.

I think that the treatment of internal and external debt should differ from the usual application in intertemporal models. Thus, in a stylized regional model, Government and external debt with their correspondent flows, internal and external deficits, should not be involved in the process that determines financial adjustment. This also means that the role of savings should differ from standard applications. In a region, the household savings decisions are independent of the regional financial system. In fact, it is more likely to be affected by national adjustment which is, of course, exogenous in a single small, open regional economy model.

The intertemporal model developed in this paper maintains forward-looking behaviour for both households and firms, and investment and saving decisions are kept separate. However, unlike standard applications, in this formulation savings follow the Solow-Swan assumption so that the rate of savings is exogenous. This does not prevent the absolute level of savings from varying through time.

Comparisons between myopic and forward-looking models are required and under particular circumstances I find that both models produce the same long-run steady-state equilibrium. This outcome differs from those reported in the existing literature (e.g., Go, 1994 and, Devarajan and Go, 1999) where the long-run impact differs in both models. The reason may be related, as I will explain later, to the asymmetric model specifications incorporated in both models. Indeed, it would seem that the intertemporal forward-looking model has generally been compared to the simple static model that lacks any capital adjustment rule and where investment is either assumed fixed to the base year level or is passive. Consequently, myopic and forward-looking models have produced different long-run impacts. However on this paper, I find the same long-run equilibrium for the myopic and the forward-looking models, although the transitional paths differ. Independently of the dynamic structure, forward-looking and myopic regional models should incorporate a separate investment function and the investment decision must be determined independently of the savings decision.

The myopic model used in this example, which follows the usual AMOS closures (McGregor *et al*. 1995, 1996), allows investment to respond to the current rate of return to capital. In addition the analysis is enriched by assuming labour supply adjustment through migration, and by investigating the role of different labour market closures.

The model proposed is calibrated on the Sardinia economy. Sardinia is the second-largest island in the Mediterranean Sea, after Sicily. It is part of the so called “Mezzogiorno” (the poor South), including regions such as Sicily, Calabria, and Campania. Its contribution to the National GDP is around 2.2% and the local population constitutes only the 2.9% of the National population. Given the small scale of the economy and the high degree of dependence from foreign sources it is plausible assuming the absence of financial adjustment mechanism making as a result household saving independents from the financial needs of the regional system.

The paper continues in Section 2 with the outline of the model structure. In Section 3 I deal with the calibration method, whilst Sections 4 and 5 are devoted to a discussion of the main outcomes of the simulations. Finally, Section 6 is a conclusion.

2. Model Description

A single-region dynamic CGE model is presented in this section. The full mathematical presentation of the model is in Appendix (A.1 - A.77).

Production and demand parameter specifications have been implemented through the well-known calibration method using the Social Accounting Matrix (SAM) for Sardinia for the year 2001[4] (Ferrari *et al*., 2009). The set of prices at which excess demand is zero is the result of an optimization process where market clearing prices equal marginal costs in each sector.

Three economic activities or sectors are considered: Primary, Manufacturing and Services[5]. No distinction is made between traded and non-traded sectors. Sardinia is a very small open economy and almost all sectors compete in the interregional and international markets. Even health care services, traditionally a sheltered sector, are now inter-regionally traded. Intermediate and primary inputs constitute the

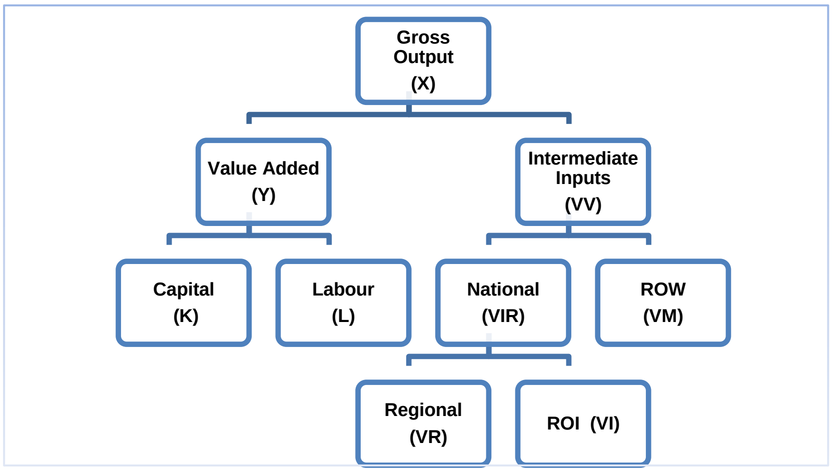
[4] In this chapter Sardinia is the economy I'm taking in consideration. However, the model can be calibrated for any small open economy. The modification of the consumer's decision problems I propose in this chapter it is of course a closure that can only be used for regions that currently cannot finance their expenditure levying taxis.

[5] The sectoral aggregation does not affect the results of the model. Since the aim of the paper is to discuss broadly the differences between myopic and forward looking dynamic models and some new consumer's closures, I have decided to not complicate the analysis with a detailed sectoral analysis, given the general purpose of the paper.

production inputs. The model also includes three domestic institutional sectors: Firms, Households and Government. External institutions are split into the Rest of Italy (ROI) and Rest of the World (ROW). I adopt assumptions typically used for a small open economy. The region is too small to affect prices in international and interregional markets and, as a consequence, the ROI and ROW prices are taken to be exogenous. The behaviour of Households and Firms is based on intertemporal optimization with perfect foresight. Government is a consolidated sector merging central and local Government levels whose expenditure can be either the result of an optimization process, where Government is simply treated as a new consumer maximizing utility subject to the budget constraints, or it is held constant in real terms.

Figure 1

The production structure of the model



Production. The model's production structure is illustrated in Figure 1. Intermediate inputs (*VV*), labour (*L*) and capital (*K*) constitute the production inputs of the model. *L* and *K* are combined in a CES production function in order to produce value added, *Y*, allowing for substitution among primary factors of production (A.17). The demand for *L* and *K* is obtained from the first order condition of profit maximization. This means that the demand for both *K* and *L* is positively related to the volume of value added, *Y*, and is a decreasing function of their prices (*rk* and *w*, respectively). Leontief technology between *VV* and *Y* is imposed (A.14), so the combination of value added and intermediate inputs can be shown with an L-shaped isoquant. Intermediate goods produced locally or imported are considered as imperfect substitutes. Basically, I mix regional and imported goods under the so called Armington assumption through a CES function. The demand function for regionally produced and imported intermediate inputs (from ROI and ROW) derives from the solution of a cost minimization problem (A.19-A.22). Regional commodities supply is bought by industries and by domestic and external institutions (A.24). That is to say, each industry in the region produces goods and services that can be exported or sold in the regional market. An export demand function closes the model where the foreign demand for Sardinian goods depends on the terms of trade effect and on the export price elasticity (A.23).

Investment. Investment decisions follow a Tobin's q adjustment. This implies that investment decisions are separated from savings decisions. According to the Tobin's *q* theory (Tobin, 1969), investments are determined as a function of the marginal *q* which is defined as the ratio of the value of additional investment goods to their replacement cost. Hayashy (1982) was able to derive the marginal *q* by solving the firm's optimization problem where firms maximize the present value of future net profits. This also means that Firms have perfect foresight, contrary to other applications where only consumers adopt rational expectation consequently deriving investment from savings.

According to Hayashy (1982) the rate of investment is a function of marginal *q* (or average *q*)[6], the ratio of the value of firms (*VF*) to the replacement cost of capital $Pk \cdot K$. With adjustment costs that are quadratic in investment, the economy does not adjust instantaneously to the desired level of capital stock. Accordingly, firms respond to the shock by making continuous small investments over time. The dynamic path of investment is the result of an intertemporal programme that seeks to maximize *VF* subject to the capital accumulation equation, $\dot{K}$ (A.50). The value of firms, *VF,* is given by the present value of the net income or cash flow, *CF*, that is to

[6] As we are assuming that the firm is price taker, the marginal *q* is equal to the average *q*. For more detail see Hayashy (1982).

say, the capital income $\pi_{i,t}$ less investment expenditure $J_{i,t}$. The investment expenditure equation (A.45) is defined as a function of the adjustment cost $\theta(x_t)$ (A.48) as in Devarajan and Go (1998), Go (1994) and Hayashi (1982). The solution to this intertemporal problem[7] produces the time path of investment (A.46) along with the law of motion of the costate variable λ (A.47).

Consumption. Individuals optimise their lifetime utility function of consumption, *C* (A.26) subject to a lifetime wealth[8]. Once the optimal path of consumption is obtained from the solution of the intertemporal problem (A27), aggregate consumption is allocated within each period and between different groups through a CES function (A.34). Household demand for regional and imported goods (A.35 and A.36) is the result of the intra-temporal cost minimization problem. According to the dynamic budget constraint, the discounted present value of consumption must not exceed total household wealth, *W*. The model distinguishes between financial wealth (*FW*) and non-financial wealth (*NFW*). So total Wealth, *W*, is given by:

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[7] The path of private investment is obtained by maximizing the present value of the firm's cash flow given by profit, π_t, less private investment expenditure, I_t, subject to the presence of adjustment cost $\theta(x_t)$ whereas $x_t = I_t / K_t$

$$Max \int_0^t [\pi_t - I_t(1+\theta(x_t))]e^{-\int_0^t r_v dv}$$

$$\text{subject to } \dot{K}_t = I_t - \delta K_t$$

The optimality conditions (or the canonic system which gives the system of differential equations in the optimal control problem) are given by the first order condition of the Hamiltonian in current value:

A. $\frac{\partial H}{\partial I} = 0 \Rightarrow J'(I_t) = \lambda_t$

B. $\dot{\lambda} = -\frac{\partial H}{\partial K} \Rightarrow \dot{\lambda} = (r_t + \delta)\lambda_t - R_t^k$

C. $\lim_{t\to\infty} \mu_t \lambda_t K_t = 0$ (trasversality condition)

The canonic system [A, B and C] can be solved to yield the costate variable in terms of discounted future revenue of capital which in turn leads to equation (5). More detail about the dynamic solution can be found in Go (1994) and Devarajan and Go (1999).

[8] In this model and in the models presented in subsequent chapters I specify perfect foresight consumer's behaviour using the conventional exponential discounting function. However, dynamic choices can also be specified using hyperbolic Euler relation as in Laibson (1998) where consumers' preferences are dynamically inconsistent since discount rate should decline as the time horizon increases.

$$W_t = NFW_t + FW_t \tag{1}$$

The NFW accumulate as follow:

$$NFW_t(1 + r_t) = NFW_{t+1} + YL_t \tag{2}$$

where YL_t is the net labour income plus transfers of income from internal and external institutions. *FW*, unlike in the standard applications, is accumulated through saving, *S* as follows:

$$FW_t(1 + r_t) = FW_{t+1} + \Pi_t - S_t \tag{3}$$

and

$$S_t = mps \cdot YH_t \tag{4}$$

where Π_t is capital income, YH_t is total household current income (that is, $YL_t + \Pi_t$) whilst *mps* is a parameter calibrated from the SAM. This way of proceeding, although allowing us to deal with an exogenous rate of household saving, is wholly consistent with forward-looking consumption behaviour. In fact, consumption still depends on lifetime income. That is to say, consumers base consumption decisions on expected future income even thought now, saving is not affected by investment and from the current account situation.

In the traditional approach (e.g. Go, 1994 and Devarajan and Go, 1999), financial wealth is obtained by assuming asset equilibrium so that financial wealth accumulates according to the following:

$$FW_t(1 + r_t) = FW_{t+1} + \Pi_t - \left(\sum_i J_{i,t} + FD_t - TB_t\right) \tag{5}$$

where *FD* is the fiscal deficit and *TB* is the trade balance. Then $\sum_i J_{i,t} + FD_t - TB_t$ gives us endogenous saving which replaces equation (2). This means that household financial wealth is equal to total assets, internal and external. That is to say:

$$FW_t = \sum_i VF_{i,t} + GD_t + D_t \tag{6}$$

In others words the wealth derived from asset holdings consists of the value of firms (*VF*), public assets (*GD*) and foreign assets (*D*). The value of firms represents the wealth generated from assets that consist of domestic firms' shares. Foreign assets reflect holdings of foreign firms' shares. The value of public assets is derived from Government bonds issued to finance the fiscal deficit.

In this formulation, as described in equation (3) and (4), the balance of payments still clears and we do not need to impose any balance of payments adjustment because the total absorption equation is sufficient to guarantee equilibrium in the payments account since I'm not considering money as a commodity. In contrast, implicit in equation (5) is the imposition of a balance of payments adjustment because savings are determined endogenously according to the financial needs of the regional system. This method is incoherent if a regional context is considered. As I have said in the introduction, it is plausible that the regional savings rate depends very much on the national economy and, unlike countries there is no saving-investment association. Furthermore, regions are unlikely to face a balance of payments problem because the multiregional capital market is highly integrated and capital moves freely across regions.

In other intertemporal models household savings have also been determined as a fixed share of income, as for instance in Go, (1994). He exploits Abel's and Blanchard's (1983) equivalence to delete the household budget constraint, solving the model as a centralized economy but imposing financial sector equilibrium and making foreign borrowing endogenous. I can also run the model as a master plan, not considering the motion equation of the state variable *W* (see Section 4).

Domestic private Assets. From Hayashi's (1982) work we know that if the firm is a price taker, then marginal *q* is equal to average *q*. Therefore we can specify the shadow price of capital λ as the ratio of the value of the firm *VF* to its capital stock *K* (A.59).

Foreign and public assets. The common hypothesis is that both internal and external debt accumulates over time in accordance with the level of deficit and interest payments. Moreover, terminal conditions for assets are imposed in order to avoid Ponzi games. As many CGEs are calibrated on steady-state equilibrium, the need to maintain a sustainable position may generate a dataset that does not reflect the real situation of the region. For instance, the calibration of the foreign asset/debt is derived by imposing regional sustainability with respect to foreign creditors or debtors. In doing this, if the regional SAM registers a trade deficit, we need to impose (and suppose) that, in the past, the region has run in surplus for many years in order to accumulate assets; the presence of a trade surplus should imply foreign debt. But several regions are in a permanent Ponzi game condition. If we do not take this situation into account, the quantitative nature of the results may change. So, if foreign debt accumulates according to the following: $\dot{D} = rD_t + TB_t$ and the trade balance *TB* is positive (so a trade deficit), a sustainable long-run position should require interest-bearing foreign assets held by the private sector. Alternatively, a negative *TB* (trade surplus) in the long-run would be able to cover interest payments on any outstanding foreign debt.

In a regional context we may suppose, instead, those capital inflows necessary to cover the trade deficit are partially constituted by subvention on which no interest is paid and that, therefore, will not reduce internal assets because these are resources coming free of charge. In Sardinia's case, trade deficits exist on both interregional and international side. Sardinia is a region that receives extensive capital subvention from the EU and the Italian Government: any payments from the Social or Structural funds of the EU are matched by the National Government. Such capital inflows are free of charge and not determined by the desire of an investor to acquire Sardinia assets. In this case the change in debt that may affect the sector financial balance should be net of this capital inflow. In modelling this situation we may assume that a proportion of debt, τ, is the amount of subvention that the region receives from the National Government or EU, and not because there is the desire to invest in the region:

$$\dot{D} = (r - \tau)D_t + TB_t \tag{7}$$

So the debt accumulates only if $TB > -(r - \tau)D_t$ and the net foreign debt is equal to the gross debt less the accumulated subvention on the assets in the gross debt.

As regards Government debt or assets, because Sardinia experiences an internal deficit, according to the usual calibration that imposes sustainability of fiscal deficits, we would need to suppose the presence of Government assets which reduce the total assets available for private agents. However for the same reasons, as explained above, we consider an "unsustainable" position as one in which the debt is going to accumulate net of the resources that the region receives from outside of the region (A.62).

Labour market regimes and labour supply. The model incorporates three labour market closures defining the form of wage setting: regional wage bargaining (RB), national bargaining (NB) and fixed real wage, (FRW). The wage-setting functions are defined below, where w is the nominal wage, *cpi* is the consumer price index, ω is a parameter calibrated to the steady-state and u is the regional unemployment rate. ε is the elasticity of wages related to the level of unemployment rate and it can also be interpreted as an index of wage flexibility.

$$\text{Wage setting}\begin{cases} ln\left[\dfrac{w_t}{cpi_t}\right] = \omega - \varepsilon \ln(u_t) & \text{(Regional Bargaining)} \\ \dfrac{w_t}{cpi_t} = \dfrac{w_{t=0}}{cpi_{t=0}} & \text{(Fixed Real Wage)} \\ w_t = w_{t=0} & \text{(National Bargaining)} \end{cases} \tag{8}$$

In the regional wage bargaining regime, the labour market is defined by the wage curve (Blanchflower and Oswald, 1994) according to which wages and unemployment are negatively related[9]. Thus regional wages are directly related to workers' bargaining power and respond to excess demand for labour. NB is a typical Keynesian closure. It assumes that the nominal wage is fixed at the base year level. We can imagine that the regional nominal wage is fixed at the value of the national

[9] See application of this closure in McGregor *et al*. (1995; 1996).

wage due to a national bargaining regime. For that reason this closure rule could be called National Bargaining (Harrigan *et al*. 1991). FRW is used to obtain an alternative counterfactual analysis. We hypothesise that the purchasing power of wages remains stable over time.

As regards demographic developments and labour supply, I assume that there is no natural population change but the labour force adjusts through a migration model commonly employed in AMOS (Harrigan *et al*., 1996, McGregor *at al*., 1996). The migration model assume the form specified in Layard *et al*. (1991) and Treyz *et al*. (1993) where zero net migration flow is taken to be positively related to ratio of the gap between the log of regional and national (w^N/cpi^N) real wages, and negatively related to the ratio of gap between the log of regional and national, (u^N), unemployment rates:

$$nim_t = \varsigma - \nu^u[\ln(u_t) - \ln(\bar{u}^N)] + \nu^w \left[ln\left(\frac{w_t}{cpi_t}\right) - ln\left(\frac{\overline{w}^N}{\overline{cpi}^N}\right)\right] \qquad (9)$$

where *nim* is the rate of net migration and ς is a parameter calibrated in order to get zero net migration in the base period. ν^u and ν^w are elasticities that measure the impact of the gap between the logs of regional and national unemployment and real wage rates.

The use of the net migration function allow for a complete labour supply adjustment. So that, in the new steady-state after the shock, the real wage (and the unemployment rate) returns back to its pre-shock value. I'm aware of the fact that the use of the net migration function has been subjected to criticism for at least two reasons. The first is related to the weakness of net migration as a statistical measure of geographical mobility. For example Rogers, (1990) point out that since net migration rate is the difference between a measure of "prevalence" (in-migration rate) and a "true rate" (out-migration flow), its interpretation is necessarily ambiguous.

The second criticism is due to the fact that individuals are heterogeneous with respect to the human capital characteristics and preferences that affect the benefits and costs of migration. For this reason, Brücker and Siliverstovs, (2003) suggest to use migration as a stock instead of flow. Partridge and Rickmann (2003) have used this type of formulation in a structural VAR model. The stock adjustment process would in this case determine the magnitude of the shift in labour supply and furthermore it would allow for incomplete migration adjustment.

3. Calibration

The model calibration process assumes the economy to be initially in steady-state equilibrium. The parameters of the models are obtained from the SAM by means of the usual calibration method. Since, in a deterministic approach, some of the parameters remain unspecified, we need to find them from outside the model, so the elasticities of substitution and other behavioural parameters are based on econometric estimation or best guesses. For all sectors, trade elasticities are set equal to 2 whilst production elasticities are equal to 0.3. The wage curve elasticity is set to -0.033, following to a recent econometric estimation reported in Devicienti *et al*. (2008), whilst in the migration function ν^u and ν^w are set equal to -0.08 and 0.06, respectively[10]. These elasticities are commonly used in AMOS and econometrically estimated by Layard *et al*. (1991).

The values of adjustment cost parameters[11] α and β in equations (A.46-9) are assigned values 0 and 1.5, respectively. The World interest rate is set to 0.04, the rate

[10] We are using parameters estimated on UK data. However this can be a good approximation for European countries. For example, the values of these parameters are almost double for the US economy (see Treyz *et al*., 1993). Furthermore, the value of these parameters does not affect the main conclusion of the paper. The paper is in fact general in scope, whatever the value of the elasticities in the migration function, the long-run equilibrium does not change. It is, of course, affected the short-run impact and the transition to a new steady state. But the magnitude of the differences between myopic and forward looking remains the same as long as the parameterization is the same in the two dynamic specifications.

[11] In many applications the parameter α is set to zero. The value of β is set to 0.9 in Dissou (2002) in a model of Senegal and in Go (1994) and Devarajan and Go (1999) in their model of Philippine is set at 2.

of depreciation to 0.07 and the inter-temporal elasticity of substitution is equal to 1.5. Given the value of total investment, *J*, as supplied by the System of National Accounts (ISTAT, 2005) through the capital matrix[12], $KM_{i,\ j}$, the equality condition with total investment by origin in the SAM holds true. The price of capital goods, *Pk*, is set equal to unity since the benchmark prices on the consumption side are set equal to one. *W* corresponds to the discounted flow of current income, *NFW* to the discounted flow of net labour income, and *FW* is obtained by maintaining asset equilibrium. By imposing equality[13] between the rate of return to capital *rk* and the user cost of capital[14], *uck*, from the constraint equations (A.28), A(.40), (A.45-49), (A59) and (A.62-67), we obtain consistent values for the variables *I*, *K*, λ, *W*, *NFW* and *FW*.

The model is solved by applying the usual procedure in solving an infinite time horizon model, by imposing steady-state conditions at a specific point in time. In the first periods I impose factor constraints in order to identify short-run impact; however the transitional pathway is the result of the discrete time solution of the model[15].

The myopic model developed here, and which is compared with the intertemporal model, is not obtained recursively, rather the equations of the model are solved simultaneously for a given finite time horizon. Since the model does not incorporate jumping variables the results are, of course, those of the recursive one. In addition, the model incorporates an adjustment cost function through which investment is determined independently of savings. The adjustment rule introduced in the myopic

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[12] For detail about the construction of the Sardinian capital matrix, see Garau and Lecca (2008).

[13] The equality between *rk* and *uck* is necessary since we are proposing the same calibration method for the myopic and the intertemporal model.

[14] Given that the interest rate and the depreciation rate are fixed, the user cost of capital depends on the variation of the capital good price, *Pk*.

[15] The model is run simultaneously for 100 periods. Since we impose capacity constraints in the short-run and labour supply adjustment through migration with analysis of different wage setting, it may take longer for a steady-state to be reached compare to conventional intertemporal CGE model that usually apply vertical labour supply closure where wages are totally flexible and labour supply fixed.

model follows that employed in AMOS (McGregor *et al*., 1996) which is consistent with the neoclassical formulation developed in Jorgenson (1963) and Eisner-Stroz (1963); the optimal path of investment is derived through the accelerator mechanism v:

$$I = v\,[K^{*} - K]$$

where K^{*} is the desired level of capital. This is wholly compatible with the Uzawa formulation of adjustment cost where the investment capital ratio (φ) is determined by the rate of return to capital (*rk*) and the user cost of capital (*uck*), allowing the capital stock to reach its desire level in a smooth fashion over time:

$$\varphi = \varphi(rk, uck)$$

$$\frac{\partial \varphi}{\partial rk} > 0; \;\; \frac{\partial \varphi}{\partial uck} < 0$$

Although Uzawa's formulation and the q theory proposed by Tobin are formally different, they are in essence "equivalent," as noted in Hayashi[16] (1982).

The myopic model can also be run for two static conceptual time closures: the Short-Run (SR) and the Long-Run (LR). In the SR, capital and labour supplies are fixed at their base year value and the initial distribution across sectors is also maintained; in the LR, factor constraints are relaxed allowing for complete capital and labour adjustment. Capital stock is at its optimum level, with rental rate equal to user cost of capital. With regard to the labour supply, the population is fully adjusted so that the system exhibits zero net migration. We also allow for perfect mobility across sectors. This kind of adjustment is quite similar to the ones presented in AMOS, a CGE for Scotland (McGregor *et al*., 1996).

[16] This equivalence allows Hayashy to integrate the two theories deriving a rate of investment function of *q*.

4. Simulation strategy

I present several simulations in order to compare different forward-looking model specifications (which are declared by an FL prefix). Comparisons between forward-looking and myopic models (MYP prefix) are also carried out. In all simulations the disturbance takes the form of a 10% increase in interregional exports. I prefer a simple demand shock since the paper is not policy oriented, but its aim is to highlight the main differences that may arise by changing the dynamic structure of the model and some household closure rules.

I present the proportionate changes from base year values for a set of key economic variables in Tables 1 and 2 for the intertemporal and myopic models, respectively. In the tables, only the short-run and long-run results are reported, along with outcomes related to the three labour market regimes: Regional Bargaining (RB), National Bargaining (NB) and Fixed Real Wage (FRW). I distinguish between models with fixed saving rate (FL1 and MYP1) and models where the saving rate is endogenous (FL2 and MYP2). The first case correspond to the model that it is more close to the of a regional economic system, while the second specification should be instead apply only to a national context. The main difference between the regional forward looking model (FL1) and its myopic counterpart (MYP1), and forward looking (FL2) and myopic (MYP2) models run with national closure is in the financial adjustment process and its implication for the balance of payments.

In FL1 I try to design a hypothetical stylized regional intertemporal model where household saving decisions do not involve any financial adjustment process. I am aware that this may change the nature of the intertemporal model. However, as I have explained above, in a regional economic framework it does not seems appropriate to incorporate household saving decisions in the manner usually applied in intertemporal models, as in equation (5).

Table 1 - Forward-Looking models. The short-run and long-run impact of 10% increase in interregional exports under three different labour market closures and three types of financial sector adjustment. Percentage change with respect to the initial staedy state.

	FL1				FL2			
	Short-Run			Long-Run	Short-Run			Long-Run
	RB	NB	FRW	RB=NB=FRW	RB	NB	FRW	RB=NB=FRW
GRP Factor Cost	0.039	0.247	0.049	1.859	0.044	0.273	0.055	2.060
Consumer Price Index	1.114	0.918	1.107	0.000	1.231	1.014	1.223	0.000
Unemployment Rate	-1.337	-8.431	-1.671	0.000	-1.496	-9.335	-1.871	0.000
Total Employment	0.149	0.937	0.186	1.956	0.166	1.037	0.208	2.155
Nominal Wage	1.159	0.000	1.107	0.000	1.282	0.000	1.223	0.000
Real Wage	0.045	-0.910	0.000	0.000	0.050	-1.004	0.000	0.000
Replacemnet cost of capital	1.073	0.861	1.065	0.000	1.193	0.959	1.184	0.000
Government Deficit	-0.004	-0.414	-0.025	-1.452	0.044	-0.409	0.021	-1.575
Labour Supply	0.000	0.000	0.000	1.956	0.000	0.000	0.000	2.155
Households Cons	-0.184	0.105	-0.174	1.480	0.006	0.326	0.017	1.849
Households Saving	1.302	1.389	1.309	1.407	-2.033	-2.215	-2.160	0.806
Financial Wealth	3.496	5.195	3.714	3.985	5.299	4.870	5.301	8.342
Non Financial Wealth	1.164	1.220	1.174	1.333	1.283	1.344	1.294	1.469
Total Wealth	1.292	1.439	1.314	1.480	1.505	1.539	1.516	1.849
Gov. Expenditure	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Current Account ROI+ROW	0.140	0.937	0.215	-3.143	0.893	1.772	0.975	-2.629
Current Account ROI	-10.746	-9.771	-10.639	-17.873	-9.567	-8.494	-9.451	-17.120
Current Account ROW	7.302	7.982	7.356	6.550	7.776	8.526	7.835	6.905
Investment	1.077	3.087	1.212	2.026	1.157	3.373	1.305	2.224
Value added								
Primary	0.963	1.797	1.002	4.980	0.916	1.837	0.959	5.130
Manufacturing	0.327	1.034	0.363	3.184	0.317	1.098	0.357	3.371
Services	0.002	0.454	0.023	1.473	0.021	0.520	0.045	1.678
Interregional exports								
Primary	6.279	6.934	6.306	10.000	6.147	6.869	6.177	10.000
Manufacturing	6.112	6.340	6.110	10.000	5.881	6.134	5.879	10.000
Services	7.520	8.140	7.544	10.000	7.186	7.870	7.214	10.000
International exports								
Primary	-3.382	-2.788	-3.358	0.000	-3.503	-2.846	-3.475	0.000
Manufacturing	-3.534	-3.327	-3.536	0.000	-3.745	-3.515	-3.746	0.000
Services	-2.255	-1.691	-2.233	0.000	-2.558	-1.937	-2.533	0.000
Investment demand								
Primary	2.772	5.792	2.997	3.184	2.711	6.034	2.958	3.371
Manufacturing	1.117	3.147	1.253	2.052	1.193	3.432	1.344	2.250
Services	0.841	2.729	0.965	1.872	0.938	3.022	1.076	2.072
Shadow price of capital								
Primary	2.331	2.790	2.372	0.000	2.400	2.906	2.446	0.000
Manufacturing	1.611	1.981	1.647	0.000	1.720	2.126	1.759	0.000
Services	1.111	1.199	1.122	0.000	1.258	1.355	1.270	0.000
Value added price								
Primary	2.071	1.698	2.055	0.000	2.149	1.736	2.131	0.000
Manufacturing	1.652	1.561	1.654	0.000	1.760	1.659	1.762	0.000
Services	1.163	0.868	1.151	0.000	1.322	0.996	1.309	0.000

Table 2 - Myopic models. The short-run and long-run impact of 10% increase in interregional exports under three different labour market closures and three types of financial sector adjustment. Percentage change with respect to the initial steady.

	MYP 1				MYP2			
	Short-Run			Long-Run	Short-Run			Long-Run
	RB	NB	FRW	RB=NB=FRW	RB	NB	FRW	RB=NB=FRW
GRP Factor Cost	0.049	0.308	0.061	1.859	0.044	0.267	0.055	2.060
Consumer Price Index	1.338	1.137	1.328	0.000	1.226	0.987	1.216	0.000
Unemployment Rate	-1.666	-10.522	-2.084	0.000	-1.514	-9.117	-1.891	0.000
Total Employment	0.185	1.169	0.232	1.956	0.168	1.013	0.210	2.155
Nominal Gross Wage	1.394	0.000	1.328	0.000	1.278	0.000	1.216	0.000
Real Gross Wage	0.056	-1.124	0.000	0.000	0.051	-0.977	0.000	0.000
Capital Good Price	1.307	1.088	1.296	0.000	1.193	0.937	1.182	0.000
Government Deficit	0.115	-0.366	0.092	-1.452	0.068	-0.377	0.046	-1.575
Labour Supply	0.000	0.000	0.000	1.956	0.000	0.000	0.000	2.155
Households Cons	0.272	0.731	0.293	1.480	0.087	0.379	0.105	1.849
Households Saving	1.587	1.749	1.595	1.407	-1.107	-0.257	-1.078	0.806
Financial Wealth	3.838	5.562	4.015	3.985	3.433	3.141	3.424	8.342
Non Financial Wealth	1.225	1.246	1.227	1.333	1.191	1.266	1.199	1.469
Total Wealth	1.369	1.485	1.381	1.480	1.315	1.370	1.322	1.849
Gov. Expenditure	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Current Account ROI+ROW	1.370	2.546	1.425	-3.143	0.661	1.268	0.701	-2.629
Current Account ROI	-8.842	-7.349	-8.772	-17.873	-9.951	-9.301	-9.903	-17.120
Current Account ROW	8.089	9.057	8.135	6.550	7.643	8.223	7.678	6.905
Investment	0.816	3.180	0.928	2.026	0.756	2.775	0.857	2.224
Value added								
Primary	0.867	1.881	0.915	4.980	0.912	1.819	0.956	5.130
Manufacturing	0.281	1.144	0.322	3.184	0.292	1.047	0.329	3.371
Services	0.047	0.616	0.074	1.473	0.029	0.512	0.053	1.678
Interregional Exports								
Primary	6.031	6.797	6.068	10.000	6.158	6.897	6.193	10.000
Manufacturing	5.751	5.984	5.762	10.000	5.968	6.297	5.982	10.000
Services	6.847	7.479	6.877	10.000	7.164	7.901	7.196	10.000
International Export								
Primary	-3.608	-2.911	-3.575	0.000	-3.493	-2.821	-3.461	0.000
Manufacturing	-3.863	-3.651	-3.853	0.000	-3.665	-3.366	-3.653	0.000
Services	-2.866	-2.292	-2.839	0.000	-2.578	-1.908	-2.549	0.000
Investment demand								
Primary	1.553	4.798	1.707	3.184	1.605	4.454	1.745	3.371
Manufacturing	0.835	3.216	0.948	2.052	0.778	2.813	0.879	2.250
Services	0.703	2.964	0.810	1.872	0.629	2.550	0.725	2.072
Rate of return to capital								
Primary	5.203	8.307	5.349	0.000	5.284	8.028	5.418	0.000
Manufacturing	2.777	5.659	2.912	0.000	2.710	5.171	2.832	0.000
Services	1.645	3.275	1.722	0.000	1.430	2.717	1.496	0.000
Value added price								
Primary	2.216	1.778	2.195	0.000	2.142	1.720	2.122	0.000
Manufacturing	1.819	1.729	1.814	0.000	1.718	1.581	1.712	0.000
Services	1.485	1.182	1.471	0.000	1.333	0.981	1.318	0.000

The outcomes obtained can also be replicated by running the model as a centralized solution by exploiting Abel's and Blanchard's equivalence (Abel and Blanchard, 1983). Such a solution has also been used in Go (1994) to remove the household budget constraint. As a result, this reduces the dimensions of the problem. Go (1994) thus closes the model by imposing equality between total savings and investment through adjustment in the level of foreign borrowing.

However, this is not the method I use. We may exploit Abel's and Blanchard's (1983) equivalence to delete the motion equation of the state variable W and resolve the problem as a centralized economy as in Go (1994), but without imposing financial sector equilibrium. This is consistent with a regional macroeconomic framework in which the constant savings rate (Solow-Swan assumption) does not involve an adjustment of the private sector financial balance, as seen above. That is, regional private assets, Government and foreign borrowing do not take part in determining the consumer's intertemporal decisions (compared with e.g. Devarajan and Go, 1999, Go, 1994 and Dissou, 2002).

Such a specification does not prevent the consumer from behaving with perfect foresight. Indeed, consumers still take decisions on the basis of future wealth, preserving the condition of instability between current consumption and wealth during the transitional pathway. Of course, in the long-run, the transversality condition is satisfied and stability restored.

MYP1 represents the traditional myopic regional model. This model, as noted above, is quite similar to the type of adjustment present in AMOS (McGregor *et al*. 1996). Household savings are a fixed proportion of income and consumption is obtained from a simple budget constraint equation.

The national configuration of the model is represented in FL2, where households are responsible for all of the financial needs of the regional system, so their financial wealth is related to outstanding foreign debt, the value of firms and Government debt. I am assuming that the Government is financing the debt by issuing bonds that are borne exclusively by households. In this case, the imposition of sectoral financial equilibrium is equivalent to the imposition of a balance of payments constraint which requires saving to adjust in order to satisfy the intertemporal payment constraint.

In order to make a comparison with a myopic formulation, in MYP2 not only the balance of payment holds, moreover I attempt to emulate the same financial adjustment that would occur in FL2. In doing so the household budget constraint equation and the financial balance equilibrium are included in the myopic model.

All models are run in order to generate an endogenous updating of the working population through migration (see equation 9). Indeed, imperfect labour markets and labour supply adjustment obtained through the introduction of quantity signals (given by the unemployment rate), and migration, are key factors in regional economic models. Such elements make regional models different to their national counterparts where the wage is often flexible and the labour supply is exogenous.

5. Simulation results

5.1. The long run impact: myopic vs. forward looking.

From Tables 1 and 2 we immediately note that, in the long run, for all closures and in all cases I obtain Leontief-type results (see McGregor *et al.*, 1996), characterized by changes in quantities but no change in prices. This reflects the complete adjustment of all factors of production. Indeed, both capital and labour endogenously adjust over time. Capital stock increases with investment which, in turn, is affected by its real shadow price. As aggregate demand rises, prices increase and so do firms' profit expectations. This leads to an increase in investment that is moderated by the replacement cost of capital reflected in the real shadow price. In-migration increases in response to a rise in real wages and falling unemployment until, in the long run, the labour market is cleared and all the increase in employment is covered by the increase in working population. In turn, the growth in labour supply puts downward pressure on wages until the labour market is in long-run equilibrium, the real wage is restored to its original level and goods' prices adjust totally.

This also means that in the long-run, the unemployment rate does not change. In the new steady state, the change in employment is equal to the change in labour supply as a consequence of the total adjustment in labour forces obtained through the net-migration function in a single region model. However, with fixed labour supply the unemployment rate should in the long run be below its initial value and so the real wage raise from the its base year value. For instance, we would also accept different labour market adjustment if a stock adjustment migration equation is incorporated.

From the tables we can also see that there are no differences in the long-run impact between myopic and forward-looking models (LR: FL1≡MYP1 and FL2≡MYP2). This equivalence arises because, in the myopic model, consumption is passive and results from the budget constraint. Its long-run value should equal that obtained in forward-looking models given that the transversality condition is satisfied, consequently eliminating divergences between current income and current consumption. On the investment side of the forward-looking model, the accumulation rate adjusts totally as Tobin's q equalizes. Such a situation corresponds, in the myopic formulation, to zero gap between desired and actual level of capital (if we adopt a Jorgenson-type adjustment) or that the change in the rate of return to capital equals that of the user cost of capital (if Uzawa-type adjustment are applied).

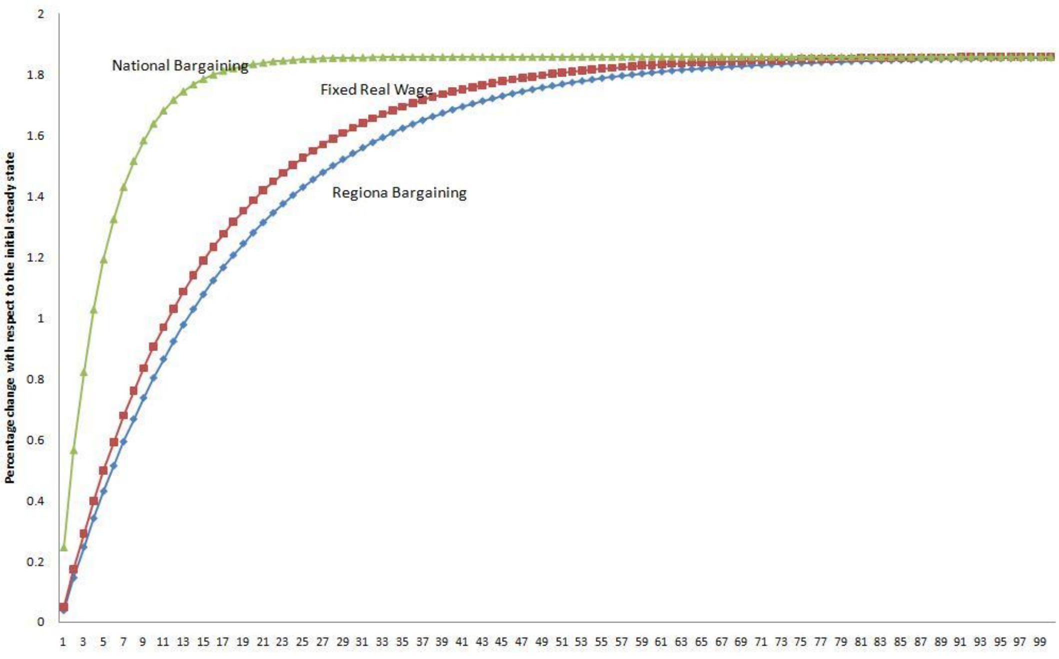
5.2. *Fixed saving rate***.**

I begin by analysing simulation results from the regional forward looking model. As I am analysing models that embody three distinct labour market closures, the main differences between these models are driven by wage dynamics. However, wage behaviour affects results only in the short run and the transitional path since in the long run labour supply adjustment allows the economy to reach Leontief-type results. Under regional bargaining and in the first period, which corresponds to the short-run solution, the demand stimulus increases labour demand which reduces the unemployment rate by 1.34% increasing, as a consequence, the bargaining power of workers and so the real wage (0.05%). For the national bargaining case, the real wage is below its initial equilibrium (-0.91%). As workers cannot bargain wages within the region, the increase in aggregate demand raises prices, thereby lowering the purchasing power of wages. In the fixed real wage scenario, the increase in the consumer price index increases the nominal wage by the same amount (1.11%).

Given that in national bargaining (NB), workers cannot bargain for higher real wages, the rise in employment and the reduction in the unemployment rate occur more rapidly than for the regional bargaining and fixed real wage cases. Furthermore, as the price of goods adjusts according to the wages dynamic by making the supply smoothly responsive, the analysis of the transitional path suggests that the capacity to reach the new steady-state faster will depend on the speed of price adjustment. In national bargaining, prices adjust faster than the other two labour market closures because nominal wages are fixed, implying less resistance to reaching their long-run equilibrium, as we can see from Figures 2 and 3.

Figure 2

Gross Regional Product, Model FL1

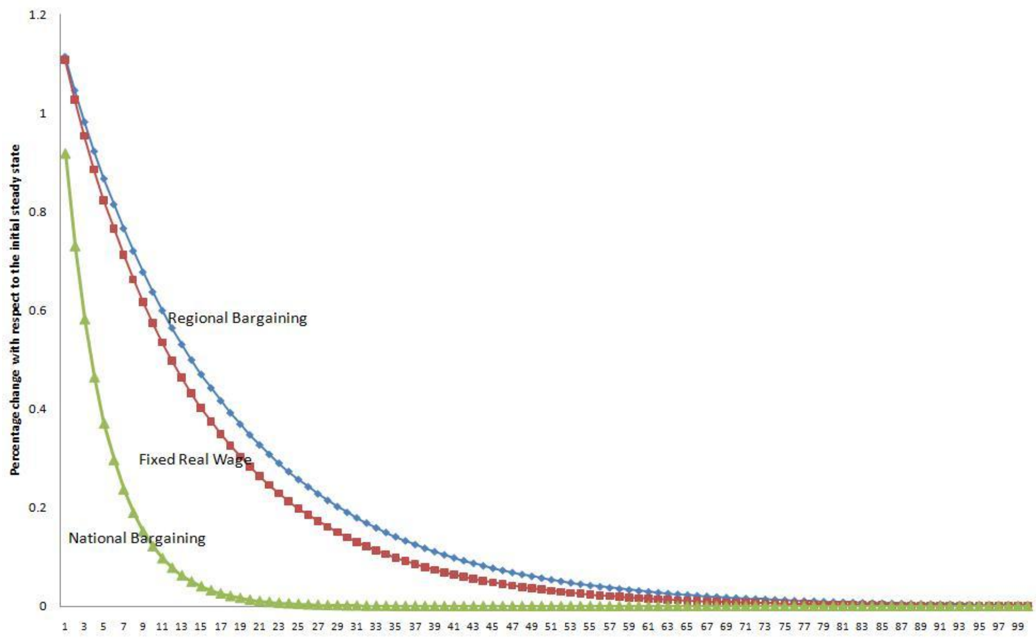


We can see that the fall in the real wage in the short-run under national bargaining has stimulating effects on the economy. In particular, this stimulates investment, so the economy adjusts more quickly under this labour market closure.

In the short-run, the increase in interregional exports is not enough to cover the rise in total imports. The total trade deficit increases and for all labour market closures the ROI trade deficit improves while the ROW deficit gets worse. This is happening as the exogenous increase in interregional exports raises competitiveness with respect to the Rest of Italy, but the augmented aggregate demand generates an increase in production that needs to be satisfied by increasing the demand for import goods. This is driven also by the increase in regional prices. The result is a substitution effect which lowers ROW exports and raises ROW imports.

Figure 3

Consumer Price Index, Model FL1



In the long-run, as prices adjust totally back to their benchmark values, the terms of trade effect is nullified, generating complete variation in interregional exports (10%) and zero change in international exports. So, as imports are increasing to satisfy production needs, the international current account get worse, generating, however, a total positive effect (current account ROI+ROW, -3.14%) given that part of the interregional current account improves by 17.87%.

In the first period, household consumption increases only for the case of national bargaining (0.10%). For regional bargaining and fixed real wage closures the proportionate change is negative. This is the distinctive impact we would expect in an intertemporal model that incorporates permanent income type behaviour; it implies that when households make decisions on current consumption, they take into consideration their future earnings, thus creating instability between current income and current consumption. Such instability disappears in the long-run where the change in consumption equals the positive variation in total wealth (1.48%).

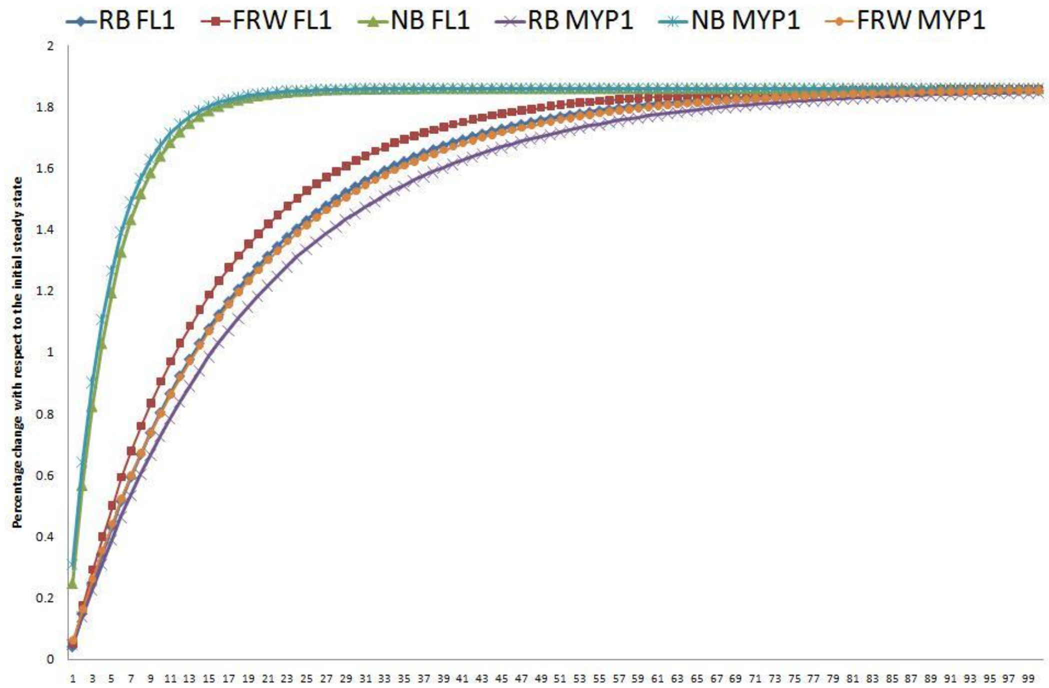
Change in the real shadow price drives the impact on investment which rises in the short- run, settling in the long-run at a level of 2.03% higher than the initial steady-state. The reason is that the increase in exports affects domestic goods prices, raising profit expectations for firms in every sector. Indeed, in the first period we see that the change in the shadow price of capital is greater than the change in the capital goods price. Furthermore, change in investment is greater in national bargaining than in the other labour market closures (*J*: NB>FRW>RB). The reason can be identified in the variation of the replacement cost of capital which is higher in regional bargaining (1.08%) and lower in national bargaining (0.86%). The national bargaining case is less sensitive to factor constraints because workers do not have the power to re-establish their purchasing power (see real wage, -0.91%) under centralized wage bargaining, leading to less upward pressure on the prices of consumption goods.

With regard to sectoral impacts, all three sectors receive permanent benefits. Breaking down the commodity composition of total exports, although the primary sector makes up the smallest share of total exports, it seems to be the sector that has the largest proportionate gains in terms of real output and investment, both in the short-run and in the long-run. Since the policy analysed here is a simple demand side shock, the initial steady-state coefficients matter for the long-run outcome. As a matter of fact, exports represent 28% of primary sector output compared to 12% in Manufacturing and 2% in Services.

By comparing the results with the myopic case we see that, as expected, they exhibit the same long-run equilibrium[17]. Furthermore, if we look at the GRP charts in Figure 4, we can see that the adjustment paths are very similar. Indeed, in both models investment is responsive to the rate of return to capital and its increase is tempered by adjustment costs. Usually, the intertemporal model is compared to the myopic model in which investment is passive and roughly determined by available savings expressed as a fixed share of income. Here instead, the behaviour of investment is quite similar in both the myopic and the forward-looking models. Furthermore, the saving rate is fixed in both the intertemporal and myopic cases.

Figure 4

Gross Regional Product: a comparison between FL1 and MYP1

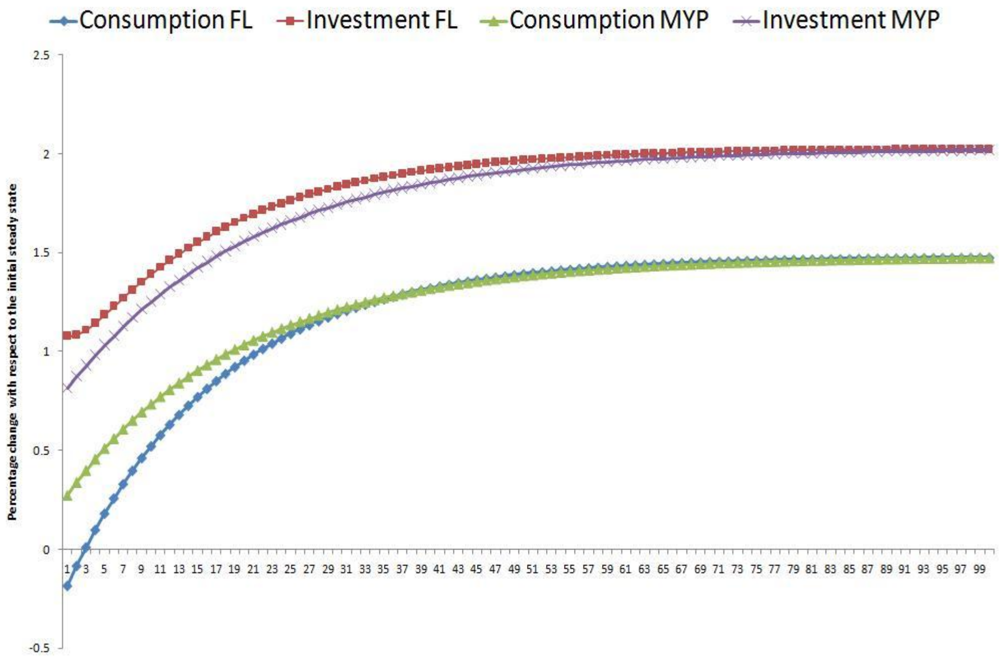


[17] These results seem in contrast with Devarajan and Go (1998) where the static and the intertemporal model produce different results.

Figure 5

Consumption and Investment under Regional Bargaining.

Myopic vs. Forward looking model



However, the transitional pathway towards the long-run may differ since, in the myopic model, agents' expectations are based on the past, whilst in the forward-looking model both consumption and the shadow price of capital depend on future conditions. In Figure 4, it can be seen that only for the case of regional bargaining and fixed real wage, the forward looking model achieves the steady-state equilibrium faster than its myopic counterpart.

In Figure 5 we can see the path of those variables subject to forward-looking behaviour, namely consumption and investment. For instance, in the regional bargaining case, only after the 30th period does consumption in the intertemporal model exceed that in the myopic model. As regards the pattern of investment, we see that, the forward looking model adjust more rapidly than its myopic counterpart.

These results, however, are strongly conditioned by the parameters of the models. In the myopic model, the adjustment parameter (which is applied to the gap between actual and desired level of capital stock) in the investment function, set to 0.5, drives the speed of adjustment; in the forward-looking model the speed of adjustment is particularly affected by the intertemporal elasticity of substitution, here equal to 1.5, that generates consumer preferences between periods. As we can see in subsection 5.4, non-necessarily model with perfect foresight reach the equilibrium faster than model specified with backward looking agents.

5.3. *Endogenous saving rate*.

When the saving rate is endogenous we are to some extent introducing an intertemporal constraint that leads to payments equilibrium through sectoral financial flows, and in turn, imposes a balance of payments adjustment constraint according to which savings depends on domestic and foreign financial assets. According to our experiment this has the effect of inverting the behaviour of saving in the short-run and raising the long-run impact of an increase in competitiveness

We do not find much difference with respect to the regional model configuration as far as the direction of the effect is concerned. This is true even for price adjustment which seems quite similar to the FL1 scenario, as does the impact of different labour market closures. The price of domestic goods drives up the increase in full consumption price and the capital goods price. Price adjustments seem more affected by the wage dynamic, as in the previous case, than by the balance of payments equilibrium constraint.

In the short-run for all labour market regimes the rate of saving falls due to the rise in trade deficit and Government deficit. In fact although investment is increasing this is not able to counterbalance the negative behaviour of the internal and external balance. So, the intertemporal constraint makes households decisions part of the regional financial mechanism even though for a region is difficult to see this kind of mechanism in operation.

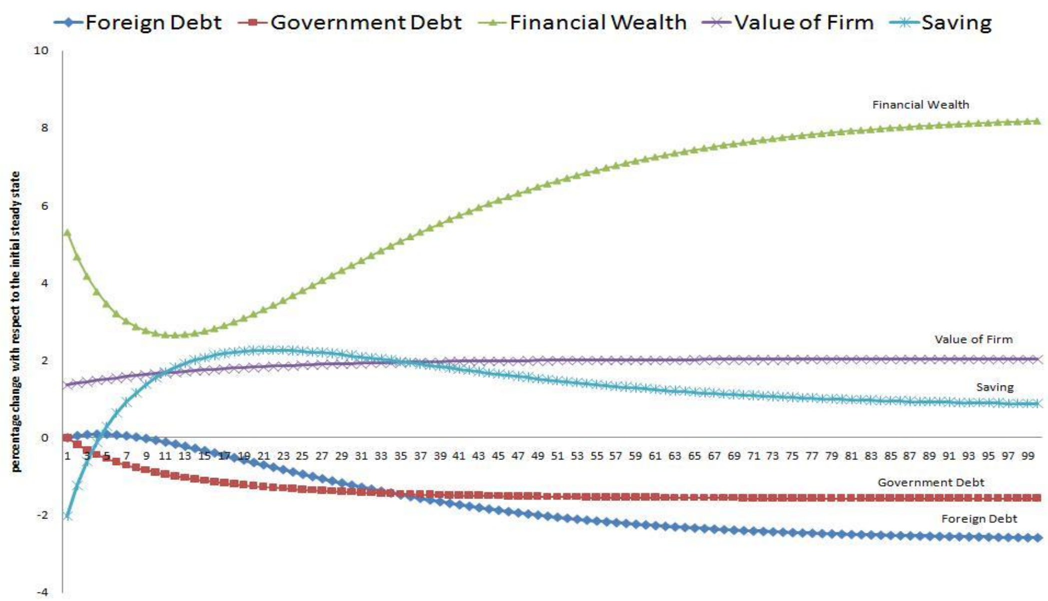
Table 1 indicates that in the long-run, we have a bigger impact in terms of real variables in national than the regional configuration. Gross Regional Product is above its benchmark equilibrium by 2.06% in FL2 and 1.91% in FL1. Such differences are driven by consumption which is greater in FL2 (1.85%) than FL1 (1.48%). So the long-run difference between the two models is due substantially to consumption, which in turn is affected by total wealth.

Wealth increases more in FL2 than in FL1. Wealth, in fact, is composed of NFW and FW. NFW is determined in the same way in both models but FW is the result of different specifications. In the national configuration, the increase in assets also raises total wealth, and consumption is positively affected. Consequently, household financial wealth increases as the value of the firm is above its benchmark equilibrium (1.97%), and the decrease in Government debt (-1.54%) is not able to offset the fall in foreign debt (-2.77%). The change in total assets is positive (see Fig. 6a). This will affect consumption since, in the long-run, the instability between current wealth and consumption disappears.

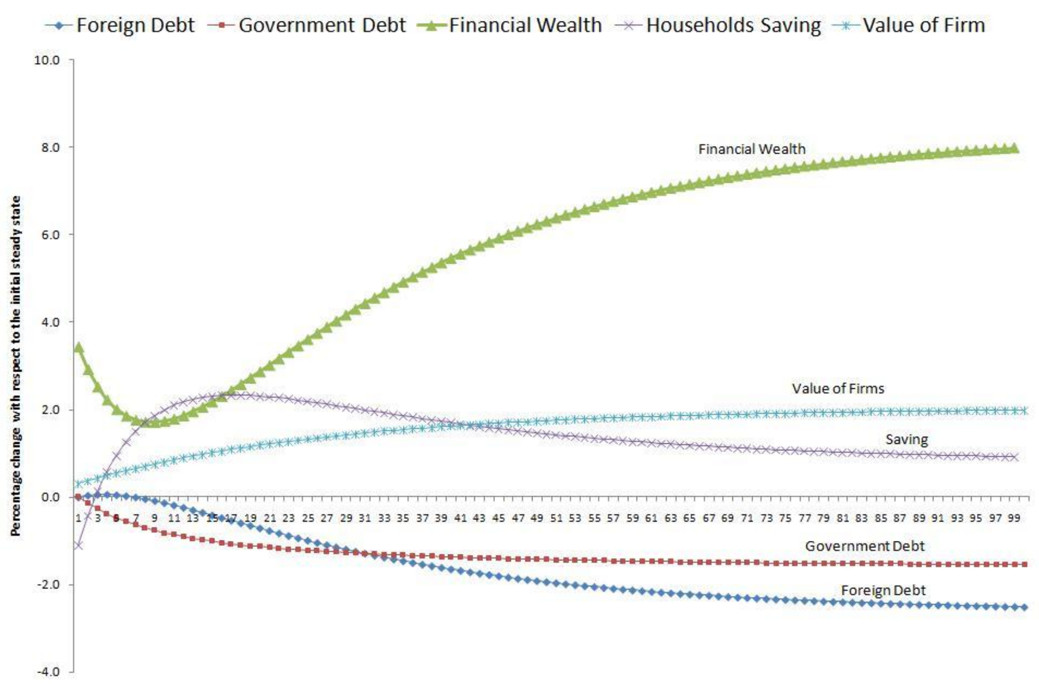
Figure 6

Financial wealth and household savings

a) Model FL2



b) Model MYP2



Surprisingly, the same type of adjustment is also obtained in the myopic counterpart of FL2. First, in the short-run, the rate of saving falls for the reason explained above and furthermore the long-run impact coincides with the forward looking model.

From Figure 6 we see that in both models, savings fall in the initial periods and then rise. Financial Wealth rises immediately in the first period and then decreases (maintaining positive change) because foreign debt rises. As soon as the change in foreign debt became negative, the financial wealth curve rises gently tempered by the fall in Government assets held by households.

This path analysis confirms that no difference in adjustment and impact exist in myopic and forward-looking models[18]. Previous literature has emphasis the incapacity of myopic model to produce consistent results based on rational behaviour. In these experiments instead I demonstrate that both models may reproduce similar behaviour for the main macroeconomic variables provided the effort to render both models comparable.

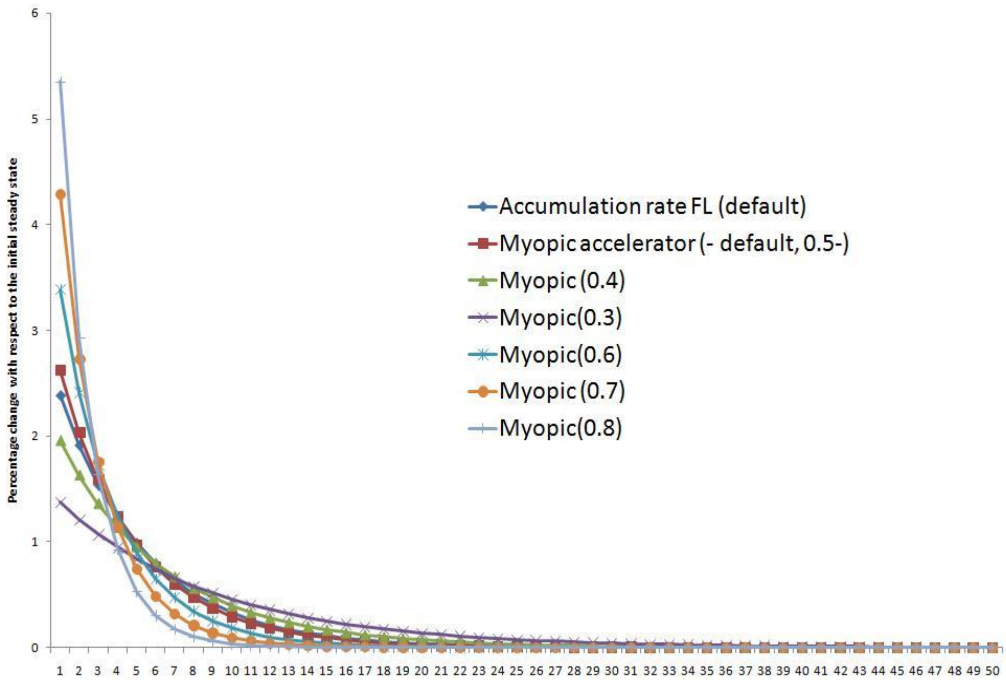
[18] We should say, however, that with supply-side shocks the adjustment path between myopic and forward looking can be dramatically different. Though, the long-run impact is the same.

5.4. *Sensitivity analysis***.**

As we have seen above, the only difference between myopic and forward-looking models is in the transitional pathway towards a new steady-state. In particular, due to the characteristics of both models, two parameters are able to govern and alter the speed of adjustment: the myopic model is highly sensitive to the parameter, v, in the investment equation, whilst the inverse of the constant elasticity of marginal utility, $1/\sigma$, is the parameter that more than any other alters the rate at which the new steady-state equilibrium is reached in the forward-looking model.

Figure 7

Accumulation rate for different value of the speed of adjustment

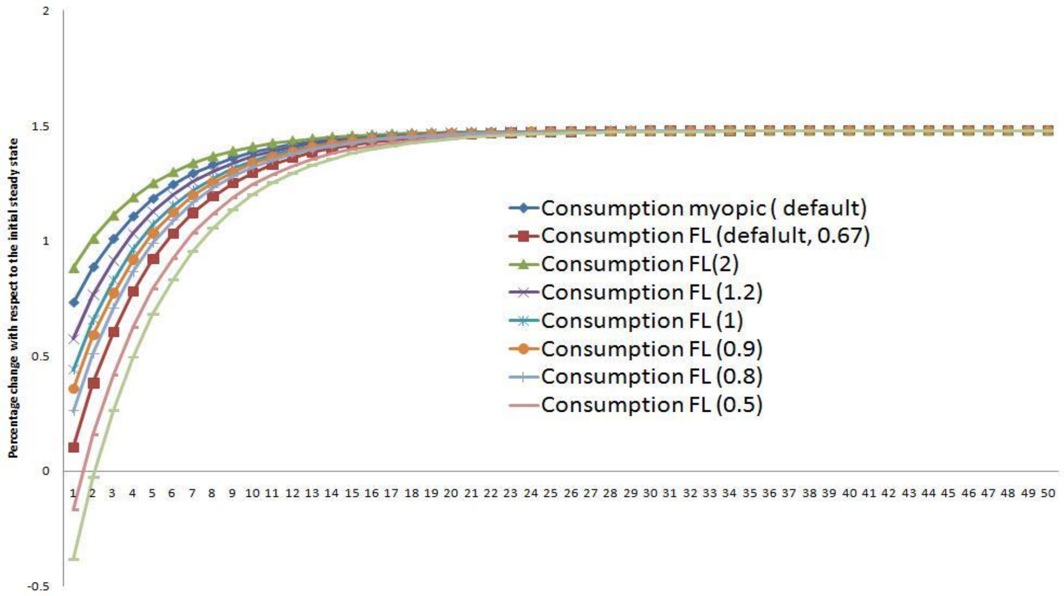


In Figure 7 and 8 I show the differences of changing the parameters v and σ in the myopic and forward looking models, respectively. As in the preceding simulations, I increase interregional exports by 10%. Increasing v the curve of the proportionate change in the accumulation rate tends to approach the stable point (zero change) rapidly. Given that capital stock accumulates over time due to past net investment, a positive shock produces a growth of GRP generating a large gap between desired and actual *K*. This causes current net investment to rise. This rise in investment will increase with the parameter υ, thereby increasing the speed of adjustment of the accumulation rate.

In Figure 8, I report the percentage change of consumption obtained by changing the value of σ. Given an intertemporally additive utility function, the Euler equation for expected utility maximization under rational expectations implies that, by increasing the value of the marginal utility of consumption and keeping fixed the *sacrifice* of not consuming (the interest rate), the cost of reallocating consumption between the present and the future will decrease. So changing σ, we modify the cost of reallocating consumption between periods that, according to the figures, imply that, for a positive shock, consumption will reach the new steady-state faster when σ is high or its inverse $(1/\sigma)$ is low. When σ is equal to 0.5 and 0.4, consumption in the initial periods falls due to the fact that households prefer to save in these periods and allocate more consumption to future periods.

Figure 8

Consumption for different value of σ



6. Final comments

Since regional CGE models are often based on a recursive dynamic structure, the lack of forward-looking expectations has been stressed as an important drawback of such models (Partridge and Rickman, 1998; 2008) the focus of this paper is to produce a simple stylized forward-looking model applicable in a regional context, given that the application of the usual mechanism and closures applied in national intertemporal CGE models would misrepresent the adjustment mechanisms that might occur in a region.

The main conclusion is that conventional intertemporal consumer optimization, based on neoclassical or Fisherian analysis of intertemporal resource allocation, seems to be inappropriate from a regional point of view. The consumer intertemporal maximization process not only yields the time path of consumption, but also the time path of savings which became a function of total financial assets. Thus, not only is the instability between current income and current consumption, related to the permanent income hypothesis approach, relevant here, but more emphasis is put on the dynamic path of savings where households are liable for all the financial needs of the region. In turn, this implies an imposed balance of payments adjustment mechanism. Furthermore, I question the plausibility, from a regional point of view, of the imposition of an intertemporal budget constraint where internal and external debts are made repayable from the private sector. No internal and external debt sustainability problems occur in a region. Deficit in the current account cannot be seen as hypothetical surplus in later periods making external debt repayable because there is no requirement to do so, and foreign debt, especially for declining regions, is the result of capital subvention supplied by supra-regional institutions, such as a national Government or the European Union. Regional public deficits are not a problem at all, given only that the national government remains committed to the maintenance of the Union. It would, therefore, be a mistake to allow consumers to take the public deficit into account in their intertemporal optimization problem, as no taxes will be imposed to cover it and no change in consumption plans is required. As

I have said above, regional policy is an exogenous variable for regions so no Ricardian equivalence of regional fiscal deficits applies.

I have also argued that some of the objections to myopic models, such as the presumed lack of capital adjustment in the myopic model and differences in long-run steady-state results between myopic and forward-looking models, cannot be correct. In some articles, forward-looking models are compared with myopic specifications that preclude any adjustment in investment and consumption. The usual assumptions are passive investment (or investment held constant to the base year in real terms) and consumption simply obtained as a fixed share of current income. In this paper, myopic and forward-looking model are quite close to each other and they generate the same results in the long-run. The only difference, though of course it may be a significant one, is in the transitional pathway where consumption and investment might diverge: perfect foresight agents have rational expectations whilst myopic foresight agents take decisions according to adaptive expectations and so make no intertemporal preferences between periods on future profits and incomes. Furthermore, from the sensitivity analysis I show that the transitional path may be affected by the two types of adjustment parameters: the speed of adjustment parameter in the myopic model and the intertemporal elasticity of substitution in the forward-looking model. In the myopic model we have an adjustment equation in investment while in the forward looking model we have two equations which influence adjustment speed, one in investment and the other in consumption. The latter can be interpreted in fact as a flexible accelerator mechanism (like for investment) where the parameter that governs intertemporal preferences, $1/\sigma$, can also be seen as an adjustment parameter. This is the main structural difference between the myopic and forward looking models presented in this paper.

It is crucial to appreciate that, independently of the dynamic structure of the model, in the long-run we obtain identical results for forward-looking and myopic models. This outcome is much more intuitive than the results obtained in the past where the two models' results were different. Such differences have been attributed to the incapacity of the myopic model to produce consistent outcomes due to the lack of perfect foresight. However, I have shown that comparable regional myopic and forward-looking CGE models produce equivalent results in the long-run and that the differences encountered in the past should be attributed to fundamental differences in model specifications, specifically to differences in macroeconomic adjustment processes.

Chapter 3

Balanced Budget Government Spending in a Small Open Regional Economy

Key words: regional computable general equilibrium analysis, fiscal federalism, fiscal policy.

JEL Classifications: C68, D58, H71, H72, R13, R50.

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1. Introduction

There is widespread movement towards at least partial fiscal federalism within the European Union and continuing debate over fiscal autonomy in Scotland. In 2008 the Scottish Parliament, with the support of the UK government, established the Calman Commission on Scottish devolution. The aim of the Commission was not only to review previous experience of Scottish devolution, but also to give comments, suggestions and recommendations on possible changes to "the present constitutional arrangements" that would improve "the financial accountability of the Scottish Parliament" (Commission on Scottish Devolution, Final report, 2009). The aim of the commission[19] is to evaluate the possibility of endowing the Scottish parliament with greater tax varying powers. At present the Scottish Parliament has the power to vary the basic rate of income tax in Scotland by plus or minus 3 pence in the pound (the Scottish Variable Rate or SVR). However, this power has not so far been used.

[19] The current UK Government is committed to implement the recommendations of the Calman Commission.

Given these developments it is particularly important to understand the probable effect of fiscal policy in regional economies that are endowed with tax varying powers. The Scottish experience represents one of the most interesting cases within the EU. It is engaged in a lively, on-going debate on greater fiscal autonomy and independence, which is politically controversial, especially in respect of tax-varying powers.

In a regional economic system, regional policy normally takes the form of an externally financed disturbance. Such a policy, of course, avoids the adverse supply side effect that typically accompanies a balanced budget expansion because the financing occurs at the level of the national economy and one assumes the target region is small[20]. While the Scottish Government has the power to vary the standard rate of income tax, it has so far chosen not to do so.

The object of this paper is to explore the likely effect of fiscal policy in Scotland in order to evaluate the conditions under which it might have a positive impact on regional economic activity. Furthermore, I wish to identify the scale, as well as the direction, of the effect of a balanced-budget fiscal expansion on the Scottish economy. Of course, there is a large literature on fiscal policy especially in the context of national economies. I study the impact of a balanced budget fiscal expansion in a regional economic context. This is an area where the literature is sparse relative to national macroeconomic analysis. The analysis uses a variant of AMOS[21] a regional intertemporal computable general equilibrium (CGE) model to study empirically a number of typical shocks affecting a small open economy in a balanced-budget framework.

[20] Scotland contributes for the 8% of the National GDP and the Scottish population is 8.5% of the whole population in UK.

[21] AMOS is an acronym for a macro-micro model of Scotland parameterised on Scottish data: the Social Accounting Matrix for the year 2004. The model employed here is an intertemporal variant of the basic AMOS CGE framework (Harrigan *et al*., 1991) discussed in Chapter 2.

In light of recent contributions to the literature that will be discussed in Section 2, the model distinguish between government current and capital expenditure, allowing different treatments of government expenditure according to its nature and purpose. In the model, current government expenditure is considered a simple purchase of goods and services so that its effect is confined to the demand side of the economy. On the other hand, capital expenditure is treated as public investment that contributes to the accumulation of the public capital stock, and consequently affects both the demand side and the supply side of the economy through its impact on productive capacity.

The existing empirical literature is mostly focussed on evaluating the impact of current purchases of goods and services. Indeed, the conventional classification of government spending into current and capital categories may be problematic in some respects. For example some of "current expenditure" on Education and Health may represent investment in human capital, resulting in the neglect of possible expansionary supply side effects arising from these expenditures.

Public current spending (including, for example, military and police expenditure, health care and education) enters in the representative utility function, as proposed by Linnemann *et al*. (2004), affecting private consumption. Government capital expenditure, through the accumulation of public investment in infrastructure, increases the substitution possibilities in production in the spirit of Barro (1990), Futugami *et al*. (1993) and Chen (2007). I also introduce congestion effects consistent with the median voter model that serve to moderate the productivity of government expenditure.

The model I develop incorporates regional economic features that differ in some respects from the previous models used to study fiscal policy shocks. The model can be considered an applied version of the skeletal model presented in Abel and Blanchard (1983). Investment decisions, that follow a Tobin's q adjustment, are separated from savings decisions. The former reflects the intertemporal optimisation of firms and the latter are the outcome of intertemporal optimisation by households.

Following Layard *et al*. (1991) the model also incorporates imperfect competition in the labour market and allows for unemployment and population updating through a net migration function. In the traditional business cycle model employed to describe the national economy, migration is absent and real wages are unrelated to the capacity of workers to restore their purchasing power and/or not associated with the capacity of the firm to use unemployment as "discipline device". Indeed, in neoclassical closures the real wage is equal to the marginal product of labour, and unemployment is not allowed since such closures typically adopt an intertemporal consumption–leisure choice. Furthermore in traditional business cycle model investments are saving driven.

The paper proceeds as follow. In the next section I briefly review previous research on fiscal policy. In Section 3 the dynamic general equilibrium model used in this study is outlined and in Section 4 I explain how congestion effects are introduced into the model. Section 5 outlines the simulation strategy and in Section 6 I discuss the results of the policy shocks. In section 7, these results are subject to sensitivity analysis and finally, in Section 8, concluding remarks are contained.

2. Review of the relevant literature.

Several empirical macroeconomic models have tried to identify the possible effects of fiscal expansion. In real business cycle models, such as in Aiyagari *et al*. (1992) and Campbell (1994), increases in government purchases lead to a decline in private consumption, showing a negative relationship between government spending and private consumption. Baxter and King (1993) find that increases in government spending significantly reduce private consumption and investment. However if the government purchases are financed by a non- distortionary tax the effect on private investment is positive. Furthermore, if government expenditures take the form of capital expenditure, the long-run effects on output, consumption and investment vary significantly depending on the productivity of public capital.

Devereux *et al*. (1996), who apply a model with increasing returns and monopolistic competition, where an increase in the level of government spending results in an endogenous increase in total factor productivity, find that government spending shocks increase private consumption. Here, the negative wealth effect of increased taxation on households is more than totally offset by the endogenous increase in total factor productivity.

Perotti (1999) found that in good times (at low levels of debt or deficit) expenditure shocks have positive, or Keynesian, effects. While negative, or non-Keynesian, effects can be found in the opposite circumstances. Blanchard and Perotti (2002), using a VAR approach, found a positive effect of government spending on private consumption and strong negative effect on private investment spending. Estimating a *q* type of investment equation Alesina *et al*. (2002) highlight the important role played by the labour market (the behaviour of wages and the response of labour supply) as a channel of transmission for fiscal policy shocks: government spending reduces private income and increases labour costs reducing profit expectations and so economic activity.

The effect of fiscal spending has also been studied analytically by introducing substitution or complementarities between government and household consumption. Linnemann and Schabert (2004) show that a positive response of private consumption might occur as a consequence of a positive government expenditure shock if the substitution between public and private consumption is sufficiently low. The degree of complementarity between private and public expenditure is identified as a critical parameter governing a positive private consumption multiplier in Ganelli and Tervala (2009).

In the previous works cited above (apart from Baxter and King, 1993 and Devereux *et al*., 1996) government spending is treated as a simple purchase of goods and services so that its effect is confined to the demand side of the economy. Arrow and Kurz (1970) initially proposed allowing public spending to accumulate over time leading to a form of investment. Following this paper a further strand of literature on fiscal policy focuses on the formation of public capital and its impact on output, private capital and consumption. The endogenous growth model of Barro (1990) that introduced government expenditure as an argument in the production function was later extended by Futagami *et al*. (1993), Baxter and King (1993) and more recently by Chen (2007). Unlike Barro, in these latest contributions public capital expenditures are treated as public investments that contribute to the accumulation of the public capital stock. Consequently these expenditures affect both the demand and supply side of the economy, through changes in productive capacity.

Many empirical studies have investigated the impact of public investment following Aschauer's work (1989a,b) that found that public capital has a powerful impact on the productivity of private capital. Indeed, while some studies support the idea that public capital has a significant impact on the productivity of private capital others reject it (for the UK, see e.g. Lynde and Richmond, 1993).

Given that public services are characterised by some degree of congestion (Barro and Sala-i-Martin 1995) it is becoming increasingly common to introduce congestion effects in order to reduce the effectiveness of public capital. Studies related to measuring the extent to which local public goods are congestable can be found in Bergstrom and Goodman (1973), and Edwards (1990). Fisher and Turnovsky (1998) analyse the effect of the different degrees of congestion on private capital and the substitutability between public and private capital in production, concluding that there exists a trade-off between them.

All the contributions mentioned so far are related to fiscal policy issues that deal with the macro-national perspective. In the regional context very few studies attempt to analyse the macroeconomic effect of fiscal policy. Previous contributions to fiscal federalism mostly adopt a micro-perspective based on the assumption of the neutral regional macro impact of fiscal autonomy, neglecting the system wide impact of regional policy (McGregor and Swales, 2005). In addition, these approaches mainly follow the national macroeconomic literature in abstracting from local wage bargaining, migration effects and regional amenities; all elements that are now crucial for the analysis of peripheral/and indeed all sub-national regions of the EU.

An example where local amenities are taken into account can be found, for the Scottish economy, in Lecca *et al*. (2010*b*) where the macroeconomic impact of a balanced-budget fiscal expansion is analysed using the bargaining theory of wage extended to incorporate the role of amenities in affecting the real bargaining process and the decision of migrants. In this study the impact of a balanced budget fiscal expansion critically depends on the value that local and potential residents allocate to public amenities. When workers are willing to give up part of their wages in exchange of more public expenditure, the sign of the balanced budget multiplier is positive, since moderation of local pay claims reduce the labour cost of labour avoiding offsetting effect of positive government expenditure.

Relevant contributions on decentralization focus primarily on intergovernmental transfers such as in the work of Boadway and Keen (1997) where, in a strategic game theory approach, interaction between different level of governments are modelled in order to define the optimal transfer of funds between levels of governments. Works that assume a macro perspective using a bi-regional CGE model but that still focus on intergovernmental transfer are those of Groenewold *et al*. (2000), Groenewold *et al*. (2003) and Groenewold and Hagger (2007).

3. Key model features

Three domestic transactor groups are incorporated: households, corporations and government; and in this application eleven commodities and activities[22]. Consumption and investment decisions reflect intertemporal optimization with

[22] Agriculture, forestry & fishing, (AGR), Mining (MIN), Manufacturing (MAN), Energy and water (ENE), Construction (CON), Distribution & catering (DIS), Transport & communication (TRA), Finance and business (FIN), Public admin etc. (PAD), Education, health and social work (EDU) and Other services (OTH). The choice of the sectoral disaggregation is mainly dictated to the need of minimizing the assumptions especially when the stock of public capital is reconstructed and to focus mainly on aggregate key macroeconomic variables

perfect foresight. Real government expenditure is divided into current and capital expenditure. While the former are treated as purchases of goods and services; the latter are explicitly considered as public investment in infrastructure. For a balanced budget fiscal expansion, the local labour income tax is endogenous. In the subsequent subsections I outline briefly the model. The mathematical presentation of the model is kept to a minimum as further details can be found in Appendix B.

3.1. *Consumers*

The decision problem for the representative consumer is to choose a sequence of effective consumption $\tilde{C}_t$, where t is the time index, that maximizes the present value of utility, as summarized by the lifetime utility function:

$$\int_0^{\infty} U(\tilde{C}_t)e^{-(\rho t)}dt \; ; \quad U(\tilde{C}_t) = \frac{\tilde{C}_t^{1-\sigma} - 1}{1-\sigma}; \tag{1}$$

discounted by the consumer's rate of time preference ρ and with constant elasticity of marginal utility σ.

Following recent analytical contributions on fiscal spending, in particular the work of Linnemann *et al*. (2004), the consumption bundle $\tilde{C}$ is defined as a CES combination over private consumption, C, and current public expenditure, G_i^*:

$$\tilde{C}_t = A \cdot \left[a^c C_t^{\omega} + (1-a^c) G_t^{*\omega} \right]^{\frac{1}{\omega}} \tag{2}$$

Using this formulation Linnemann *et al*. (2004) show that if the elasticity of substitution $\varepsilon = \dfrac{1}{1-\omega}$ is sufficiently low, an increase in government purchases in goods and services can raise the marginal utility of private consumption and counteract the negative wealth effect on consumption due to an increase in taxation.

The present value of consumption must not exceed total wealth, *W*. I distinguish between financial wealth (FW) and non-financial wealth (NFW), such that $W_t = NFW_t + FW_t$ and in which:

$$NFW_t(1+r_t) = NFW_{t+1} + (1-\tau_t)L_t^s \cdot (1-u_t) \cdot w_t + \sum_h \sum_{dngins} TRSF_{h,dngins,t} + \sum_h TRG_h \cdot Pc_t + \sum_h REM_h \varepsilon - \sum_{dngins} \sum_h TRSF_{dngins,h,t} \tag{3}$$

The variables $L_t^s, w_t, TRSF_{h,dngins,t}$, u_t and τ_t are respectively working population, nominal wage rate before tax, the transfer matrix between households (*h*) and domestic no-governmental institutions **(***dngins*), the unemployment rate and the rate of income tax. The transfer from the Government (*TRG*), remittance (*REM*) and the exchange rate (ε) are fixed.

Financial Wealth (*FW*) evolves as follows:

$$FW_t(1+r_t) = FW_{t+1} + \Pi_t - S_t \tag{4}$$

where Π_t and S_t are respectively capital income and saving. In the model saving is obtained as a function of the current level of income[23].

Once the optimal path of consumption is obtained, the aggregate consumption is allocated within each period for the *i* commodities and for five different groups of income. Household demand for regional and imported goods is the result of the intra-temporal cost minimization problem.

[23] Consumers base consumption decisions on expected future income, and although saving is not affected by investment and from the current account situation, it still allows the consumers to smooth consumption across periods. In the traditional approach, financial wealth is obtained by assuming asset equilibrium. It does not means that in our formulation, the balance of payments do not clear. Indeed, we do not need to impose any balance of payments adjustment because the total absorption equation is sufficient to guarantee equilibrium in the payments account since we are not considering money as a commodity. More details on this can be found in Chapter 2.

3.2. Firms

Total gross output *X*, is given by combining value added (*Y*) and intermediate inputs (*V*) through Leontief technology:

$$X_{i,t} = \min\left\langle \frac{Y_{i,t}}{a_i^Y}; \frac{V_{i,t}}{a_i^V} \right\rangle \tag{5}$$

where a^Y and a^V are input coefficients. *Y* is given by a CES[24] combination of labour (*L*), private capital (*K*) and public capital services ($K^d_{(g)}$) :

$$Y_i = CES(L_i, K_i, K^d_{(g)}) \tag{6}$$

I maintain constant return to scale, and $K^d_{(g)}$ is treated as an unpaid factor of production that is considered exogenous to the firm and determined by the public stock of infrastructure $K^s_{(g)}$ that accumulates over time subject to depreciation $\left(\delta_{(g)}\right)$ through capital government expenditure $I_{(g)}$:

$$K^S_{(g)t+1} = K^S_{(g)t} \cdot (1 - \delta_{(g)}) + I_{(g)t} \tag{7}$$

The representative firm considers public capital as exogenous and the path of private investment is obtained by maximizing the present value of the firm's cash flow given by profit, π_t, less private investment expenditure, I_t, subject to the presence of adjustment cost $\theta(x_t)$ whereas $x_t = I_t / K_t$ as in Chapter 2.

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[24] In this model a choice was made to consider public capital as one of the three inputs in a CES function allowing substitution with the other conventional inputs (labour and capital). It could be argued that it would be better to use a hierarchical production function by nesting a series of CES functions where, for example, at the lower level a composite input is the result of substitution between private and public capital and at the upper level the composite is a substitute for labour. Of course it would also have been possible to perform an opposite example where the composite input is given by labour and private capital. Assuming one of the possible hierarchical specifications it would also imply that we are aware of the exact form and relationship to assign. However, we do not attempt to estimate econometrically all the possible relationships. For this reason we prefer to use the CES formulation keeping the elasticity of substitution between inputs low and equal to 0.3. In fact, independently of the position of public capital in different levels of the hierarchy, if we maintain the same value of the elasticity of substitution in the nests, the results do not change since it would be the same as a single nest.

3.3. Government

As I have said above there is a distinction between two kinds of government expenditures: G^* and $I_{(g)}$. Government keeps a balanced budget year to year, so that government expenditures are entirely financed by distortionary taxation. I consider the case where government finance its expenses (current and capital) by raising exclusively the rate of tax on labour income, ire_t.

Transfers to and from other institutions are constant in nominal terms but I allow to vary in real terms.

3.4. Population and Labour Market

No natural population change is assumed, but the labour force (*LS*) evolves over time through the migration model specified in chapter 2 eq. (9). The migration model starts with zero net migration flow and, in any period, migration is taken to be positively related to the gap between the log of regional and national (w^N/cpi^N) real wages, and negatively related to the gap between the log of national, (u^N) and regional unemployment rates u where u^N, w^N and cpi^N are are not time-varying.

As in Chapter 2, wage setting is determined via a regional bargained real wage function that embodies the econometrically derived specification given in Layard *et al*. (1991)[25]:

$$\ln\left(\frac{w_t}{cpi_t}\right) = c - 0.113 \cdot \ln(u_t) \qquad (8)$$

where c is a calibrated parameter. Thus, in the regional wage bargaining regime (RB), the labour market is defined by the wage curve (Blanchflower and Oswald, 1994) according to which wages and unemployment are negatively related.

[25] This elasticity is different from the Sardinian case (see Chapter 2).

I also consider the case of National bargaining where nominal wage is kept fixed throughout.

3.5. Model parameterization.

The demands for Scottish goods are determined via an export demand function according to which the quantity of goods exported is related to the relative regional price, given constant prices and income for the Rest of UK and the Rest of the World, and a price elasticity of 2.0. Domestic and imported inputs are obtained via an Armington link (Armington, 1969) and are therefore relative-price sensitive.

The values of the adjustment cost parameter in the investment function, z is assigned a value of 1.5. The world interest rate is set to 0.04 (which is faced by producers, consumers and investors), the rate of depreciation to 0.1 and the inter-temporal elasticity of substitution is equal to 1.5. In the benchmark equilibrium the price of capital goods, is set equal to unity since the benchmark prices on the consumption side are set equal to one.

The model parameterization procedure considers the economy to be initially in steady-state equilibrium. The benchmark data set is the Scottish Social Accounting Matrix (SAM) for the year 2004 based on the IO Table for 2004 built by the Scottish Government[26] to which I have added the information related to the primary and secondary income distribution using the household's disposal income account[27]. The government fiscal deficit is derived from the Scottish net borrowing account[28]. In this account it emerges that the estimated Scottish fiscal deficit is 12.0 per cent of GDP (excluding oil revenues). As regards the capital inflow, these are obtained as net imports. Once a preliminary SAM is obtained, a Cross Entropy model (Robinson *et al.*, 2001) is used to readjust and introduce new information and constraints in some

[26] http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/Input-Output/Downloads

[27] http://www.scotland.gov.uk/Topics/Statistics/Browse/Economy/SNAP/expstats/GDHI2007

[28] http://www.scotland.gov.uk/Publications/2006/12/11084016/7

sub matrices of the SAM. The constraint equations allow us to maintain invariant the original IO and the household primary and secondary income distribution, which come from official data. Also constraint equations are used to avoid transfers of income between domestic and foreign institutions affecting the relative composition of the capital account of the balance of payment. The final Scottish SAM is in Appendix B, Table B.1.

For all sectors, trade elasticities are set equal to 2 (Gibson, 1990) whilst production elasticities are equal to 0.3 (Harris, 1989). The wage curve elasticity is set to -0.113, whilst in the migration function, I use the elasticities econometrically estimated by Layard *et al*. (1991). The benchmark value of *W* corresponds to the discounted flow of current income, *NFW* to the discounted flow of net labour income, and *FW* is obtained by maintaining asset equilibrium.

I apply the usual procedure to solve an infinite time horizon model, by imposing steady-state conditions at a specific point in time. In the initial period, factor constraints are imposed, in order to identify short-run impacts.

4. Modelling congestion effects

To allow for congestion effects and to take into account the degree of *non-publicness* of public goods (Bergstrom and Goodman, 1973), public capital stock and current government expenditure are adjusted following a simple model consistent with median voter demand studies (see Edwards, 1990 and Fisher and Turnovsky, 1998). The congestion model I use follows the traditional formulation of decreasing marginal congestion. The aggregate public capital service is adjusted for congestion by the change in private capital stock, $\dot{K}$, and population, $\dot{LS}$, while, current government expenditure, G^*, is congested only by population[29]:

[29] In some studies which hold labour supply fixed, public capital is congested only by private capital (Barro and Sala I Martin, 1993 and Fisher and Turnovsky, 1998). Other formulations may imply congestion only if population increases (Bergstrom and Goodman, 1973 and Edwards, 1990) or by employment and private capital (Glomm and Ravikumar, 1993). Since the model used here allows for unemployment, public capital is congested by private capital and total labour force (which includes

$$K_{(g)}^{d} = K_{(g)}^{s} \cdot \left[\dot{K} + \dot{LS} \right]^{\gamma} \qquad \gamma = \frac{\eta - 1}{\eta}, \ \gamma \in (0, -\infty) \quad \eta \in (0,1). \tag{9}$$

$$G_i^* = G_i \cdot \left[\dot{LS} \right]^{\gamma} \tag{10}$$

where, γ is the congestion parameter. The increase in private capital and population reduce the effective quantity of public capital stock enjoyable by all firms and the magnitude of this effect depends on the level of η. When $\eta = 1 (\gamma = 0)$ we have the case of a pure public good, which is available equally to each firm and its use would not reduce its usefulness to others. In this case the public capital service is non-rival and non-excludable as defined by Samuelson (1954) and firms enjoy full benefits from its use. If $\eta = 0.5 (\gamma = -1)$ public capital still remains non-excludable but loses the property of non-rivalry[30]. The quantity of public services available to a producer declines if capital and working population increase. The higher is the use of private factors the lower is the contribution of public capital in production. Such a crowding effect is stronger the lower is η which has the smallest value where there is a situation of "over-crowding" (Edwards, 1990) such that the decline in public services is faster than the increase in growth.

Here, public investment is chosen exogenously, and public capital stock is treated as an unpaid factor of production subject to congestion, where $\eta = 0.5$. In other CGE models, as for example in Alonso-Carrera *et al.* (2009), the congestion parameter is set equal to 0.36 while three levels of congestion parameter (high, medium and low) are analysed in Seung and Kraybill (2001). Since specifically estimated parameters for the Scottish economy are not available I prefer, in these circumstances to take the intermediate situation of *proportional congestion* ($\eta = 0.5$) as a benchmark.

the unemployed). In the model, all population is working-age population. So I use labour force and population as synonymous.

[30] This corresponds to the case described in Fisher and Turnovsky, (1998) called *proportional congestion*.

However, I handle the uncertainty associated with the value of this parameter in subsequent sections, where a sensitivity analysis is carried out on the parameter η.

The effective level of current government expenditure depends only on population, which is endogenous in the model. In no circumstances can the effective level of government service be negative.

Unfortunately, I do not have data on the level of the Scottish public capital stock, so I have to develop a proxy. The approach employed to estimate the government public capital stock is the general perpetual inventory method (detailed in Appendix B), a well-known methodology applied by OECD (2001) and by the U.S. Bureau of Economic Analysis (1999)[31].

5. Simulation strategy

According to the 2004 HM Treasure Budget estimate, the amount of revenue that the Scottish tax office would be able to collect for one penny rise in the Scottish variable tax rate would be approximately £270 million of additional revenue which represent 1.10% and 12.20% increase in current and capital government expenditure, respectively. I separately analyse the effects of 1.10% and 12.20% increase in capital government expenditure. I will also simulate the impact of a simultaneous increase of both current and capital public expenditure.

It seems reasonable, in the first instance, to compare the situation under which regional policy is financed outwith the region, with the case in which it is internally financed. So, I initially investigate an externally financed 1.10% increase in current government expenditure (Scenario 1). Subsequently, I analyse the case of an increase in current government expenditure locally financed. So that, income tax should rises by the amount necessary to cover a permanent 1.10% increase in current purchases in goods and services. I distinguish between the case where current government expenditures do not enter in the consumers' utility function (Scenario 2) and the

[31] See also Holtz-Eakin 1993 and Kamps, 2004.

case in which current government expenditure affects the marginal utility of consumption to a degree determined by the elasticity of substitution of the consumption bundle defined over private and public consumption (Scenarios 3 and 4).

Our results critically depend upon the value assigned to the elasticity of substitution, ε. Many studies estimate the degree of substituibilty between private and public consumption (e.g. Kormendi, 1983; Aschauer, 1985; Karras 1994; Ni 1995; Ho, 2001; Fleissing and Rossana, 2003) however the estimates found in the literature vary widely[32]. Moreover, I cannot use previous estimates directly because they are based on parametric specifications that are not consistent with our model. Indeed, most of the estimates are obtained assuming an intra-temporal linear utility function (such as $\tilde{C} = C + \varepsilon \cdot G$) whilst our model is assuming that private and public consumption are imperfect substitutes, to accommodate the analytical findings of Linnemann and Schabert (2002). For this reason I compare two outcomes obtained by imposing $\varepsilon = 0.2$ (Scenario 3) and $\varepsilon = 2$ (Scenario 4).

In the next experiments (Scenarios 5), I simulate an internally founded 12.20% increase in public investment that consequently affects the public capital stock, which enters into the aggregate production function. Government current consumption is fixed and so there is no effect on the marginal utility of consumption.

I also show results of a simultaneous increase in current and capital government expenditure (Scenario 6). At present, the Scottish Parliament does not have complete discretion regarding the allocation of the Scottish budget between capital and current spending, which is determined by the UK Government (Report on Scottish Devolution, 2009). So, according to the Government Expenditure and Revenue Scotland (GERS, 2009), only 12% of the budget is allocated to public capital expenditure while the rest is made up of current purchase in goods and services. Here I hypothesize that the increment of revenue that would occur by raising the Scottish

[32] Some of them show that substituibility would best describe the relationships between public and private spending while others are clearly supporting the case of complementarity.

variable tax of one penny is allocated 88% to current expenditure and 12% to capital expenditure, which correspond to a permanent increase of 1.03% and 1.07% of current and capital expenditure respectively.

6. Policy analysis

Results for a number of short and long-run simulations are reported in Table 1. The first two columns of Table 1 report the impact of an externally financed increase in government current expenditure. In Scenarios 2, 3 and 4, of Table 1, I investigate the effect of an increase in current government purchases in goods and services but imposing a balanced Government budget. In Scenario 5, the tax rate rises in order to cover a permanent 12.20% increase public investment and finally in Scenario 6, I analyse the case of a simultaneous increase in current and capital government expenditure.

6.1. The impact of a permanent, externally funded increase in government expenditure.

I start by considering the outcome of an exogenous, permanent, unanticipated and externally founded increase in government expenditure. In the short-run the demand disturbance has an expansionary effect on gross regional product (0.16%) and employment (0.25%). As labour demand increases, the unemployment rate falls by 1.87% and the real wage increases by 0.21%. Output does not expand in all sectors and the extensive crowding out of exports results from the increase in regional prices. Whilst the rise in commodity prices also increases the replacement cost of capital, the positive change in the real shadow prices of capital in some sectors contribute to the formation of profit expectations resulting in an increase of aggregate investment.

Table 1

Short-run and long-run results for key variables. Percentage change with respect to the initial steady-state.

	Externally financed		*Balanced budget finance*											
			Current government expenditure shock								*Capital government expenditure shock*		*Current and capital government expenditure*	
	Scenario 1		**Scenario 2 (basecase)**				**Scenario 3**		**Scenario 4**		**Scenario 5**		**Scenario 6**	
Key parameters			ε→∞				ε=0.2		ε=2		η =0.5		ε→∞ η =0.5	
Labour market closures	**RB**		**RB**		**NB**		**RB**		**RB**		**RB**		**RB**	
Time	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
Income tax	0.00	0.00	2.83	3.57	2.02	2.15	1.33	1.53	2.15	2.61	1.94	0.47	2.56	2.34
GRP Income measure	0.16	0.37	-0.06	-0.75	0.15	0.12	0.15	0.27	0.03	-0.27	-0.03	0.65	0.04	0.09
Consumer Price Index	0.05	0.00	-0.03	0.08	-0.01	0.00	0.11	0.03	0.03	0.06	0.05	-0.10	0.04	0.03
Unemployment Rate	-1.87	0.00	0.67	0.00	-1.76	-0.28	-1.70	0.00	-0.40	0.00	0.51	0.00	-0.38	0.00
Total Employment	0.25	0.42	-0.09	-0.72	0.24	0.18	0.23	0.29	0.06	-0.25	-0.07	0.45	0.10	0.10
Nominal Gross Wage	0.27	0.00	0.39	0.70	0.00	0.00	0.53	0.30	0.45	0.51	0.33	-0.02	0.53	0.44
Nominal Wage after Tax	0.27	0.00	-0.10	0.08	-0.35	-0.37	0.30	0.03	0.08	0.06	-0.01	-0.10	0.09	0.03
Real Gross Wage	0.21	0.00	0.42	0.62	0.01	0.00	0.43	0.27	0.42	0.46	0.28	0.08	0.49	0.41
Real Wage after Tax	0.21	0.00	-0.07	0.00	-0.34	-0.37	0.19	0.00	0.05	0.00	-0.06	0.00	0.04	0.00
Replacment cost of capital	0.05	0.00	0.01	0.06	0.01	0.00	0.08	0.03	0.04	0.04	0.04	-0.10	0.10	0.06
Working population	0.00	0.42	0.00	-0.72	0.00	0.14	0.00	0.29	0.00	-0.25	0.00	0.45	0.00	0.10
Households Consumption	0.26	0.34	-0.96	-1.12	-0.37	-0.38	0.77	0.81	-0.18	-0.22	0.17	0.39	-0.23	-0.22
Government Consumption	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	0.00	0.00	1.03	1.03
Private Investment	0.56	0.29	-1.28	-0.82	0.08	0.01	0.56	0.23	-0.43	-0.33	0.22	0.61	-0.09	0.03
Public investment	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.20	12.20	1.07	1.07
Output														
Agriculture	-0.03	0.11	-0.11	-0.99	-0.01	-0.09	-0.06	-0.05	-0.09	-0.55	-0.01	0.90	-0.02	0.09
Mining	*-0.16*	*0.07*	-0.28	-1.16	0.01	-0.01	-0.33	-0.33	-0.30	-0.77	-0.02	0.90	-0.03	0.09
Manufacturing	*-0.13*	*0.06*	-0.22	-1.72	0.00	-0.01	-0.26	-0.59	-0.24	-1.19	-0.09	0.80	-0.15	-0.13
Energy	*-0.02*	*0.17*	-0.10	-0.90	-0.01	-0.07	-0.03	0.08	-0.07	-0.44	-0.01	0.87	-0.02	0.07
Construction	*0.09*	*0.29*	-0.27	-0.91	0.11	0.11	-0.01	0.05	-0.15	-0.46	0.06	0.99	-0.04	0.05
Distribution	*0.04*	*0.28*	-0.51	-1.18	-0.14	-0.27	0.17	0.47	-0.20	-0.41	-0.01	0.61	-0.16	-0.14
Transport	*-0.04*	*0.24*	-0.29	-1.07	-0.03	-0.08	-0.07	0.16	-0.19	-0.49	-0.05	0.77	-0.10	-0.03
Financial	*-0.02*	*0.22*	-0.14	-0.94	-0.01	-0.08	-0.05	0.18	-0.10	-0.42	-0.04	0.64	-0.09	-0.12
Public admin	*0.99*	*1.04*	0.95	0.93	0.99	1.01	0.98	1.03	0.97	0.98	0.00	0.13	0.78	0.86
Education	*0.66*	*0.85*	0.41	0.34	0.61	0.69	0.69	0.87	0.54	0.59	-0.04	0.29	0.36	0.47
Other services	*0.01*	*0.30*	-0.28	-0.88	-0.02	-0.05	0.02	0.32	-0.15	-0.32	-0.03	0.80	-0.06	0.03
Total Export (RUK+ROW)														
Agriculture	-0.11	0.00	0.28	-0.45	0.10	0.00	-0.28	-0.19	0.03	-0.33	-0.08	0.79	0.09	0.22
Mining	-0.21	0.00	-0.28	-0.70	0.00	0.00	-0.40	-0.30	-0.33	-0.51	-0.01	0.68	0.00	0.15
Manufacturing	-0.19	0.00	-0.14	-1.74	0.01	0.00	-0.38	-0.74	-0.25	-1.27	-0.14	0.76	-0.15	-0.14
Energy	-0.15	0.00	0.28	-0.26	0.07	0.00	-0.32	-0.11	0.01	-0.19	-0.05	0.74	0.07	0.18
Construction	-0.57	0.00	0.25	-0.52	-0.30	0.00	-0.59	-0.22	-0.14	-0.38	-1.13	-0.19	-0.47	-0.18
Distribution	-0.51	0.00	0.71	-0.73	0.36	0.00	-1.23	-0.31	-0.17	-0.53	-0.47	0.69	0.03	0.01
Transport	-0.29	0.00	0.06	-0.70	0.06	0.00	-0.60	-0.30	-0.24	-0.51	-0.17	0.68	-0.07	0.03
Financial	-0.28	0.00	0.35	-0.58	0.09	0.00	-0.56	-0.25	-0.07	-0.42	-0.21	0.44	-0.05	-0.15
Public admin	-1.35	0.00	-1.43	-0.58	-1.06	0.00	-1.62	-0.25	-1.52	-0.43	-0.46	2.45	-4.89	-2.76
Education	-1.02	0.00	-1.01	-1.01	-0.54	0.00	-1.49	-0.43	-1.22	-0.74	-0.46	1.16	-2.02	-1.31
Other services	-0.47	0.00	0.14	-0.79	0.04	0.00	-0.91	-0.34	-0.34	-0.58	-0.28	1.01	-0.17	0.00

When I allow the labour force to adjust through migration and the capital stock updating through investment, the economy gradually approaches the long-run equilibrium. The region returns to a zero net migration steady-state position and investment approaches the level required to just cover depreciation. At this point, real wages and prices return to their original values and the unemployment rate is invariant with respect the initial steady-state. These results are driven by the combination of the zero net migration and real wage bargaining function. As migration increases due to a fall in unemployment and a rise in real wages, the labour force expands. During the transitional path, variation in the employment-labour force ratio declines gradually and returns to its original level where migration falls to zero.

As a result of the positive in-migration, the real wage is subject to downward pressure, until the labour market achieves its long-run equilibrium where the positive change in employment is totally absorbed by migrants. So that the real wage is restored to its steady position and the price of goods are fully adjusted.

Relaxing the capital constraint, capital stock increases with investment which in turn, is affected by its real shadow price. As aggregate demand rises, prices increase and so do firms' profit expectations. This leads to an increase in investment that is moderated by the replacement cost of capital until Tobin's q is again equal to 1 and accumulation is complete. In the long-run the system behaves "as if" it were an extended input-output system because across such equilibria there is effectively an infinitely elastic supply of labour and capital (Batey and Madden, 1983; McGregor *et al*. 1996).

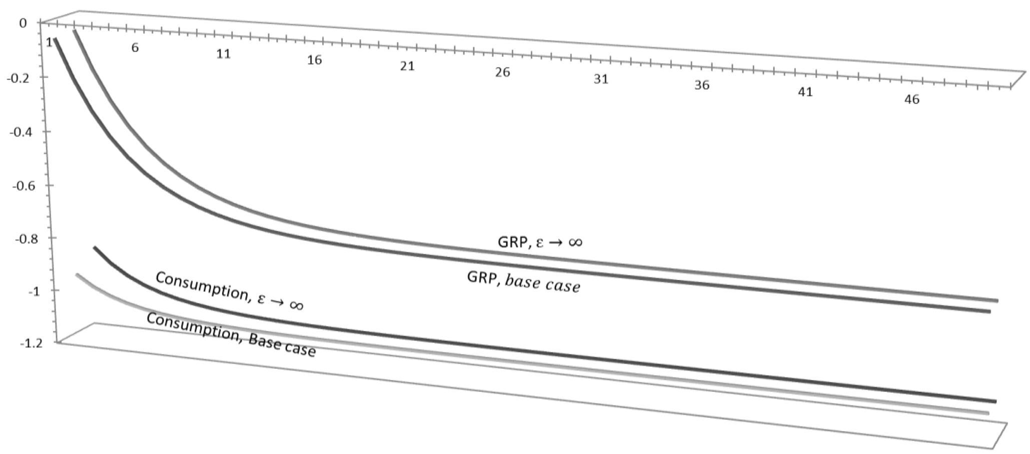
6.2. *The impact of a permanent increase in current government spending founded by an increase in regional income tax: the case of perfect substitution between private and public consumption.*

I next consider the case that shows the response of the regional economy to an increase in current government expenditure that is financed by an increase in labour income tax introduced at the level of the region. Public capital is trivial and current government purchases of goods and services do not enter in the household utility function. The results we would expect when the utility function is defined over a consumption bundle $\tilde{C}$ where perfect substitution between private and public consumption is imposed ($\varepsilon \to \infty$) are those where government purchases do not enter in the individual utility function.

Figure 1 shows the change in GRP and consumption due to an internally financed 1.10% increase in current government expenditure. The change in GRP and consumption when $\varepsilon \to \infty$ approximates the case in which public spending has no impact on household utility. From the chart it seems that the percentage changes are almost equal in the two cases and will converge in the new steady-state.

Figure 1

Consumption and investment comparison between the base case scenario and perfect substitution.



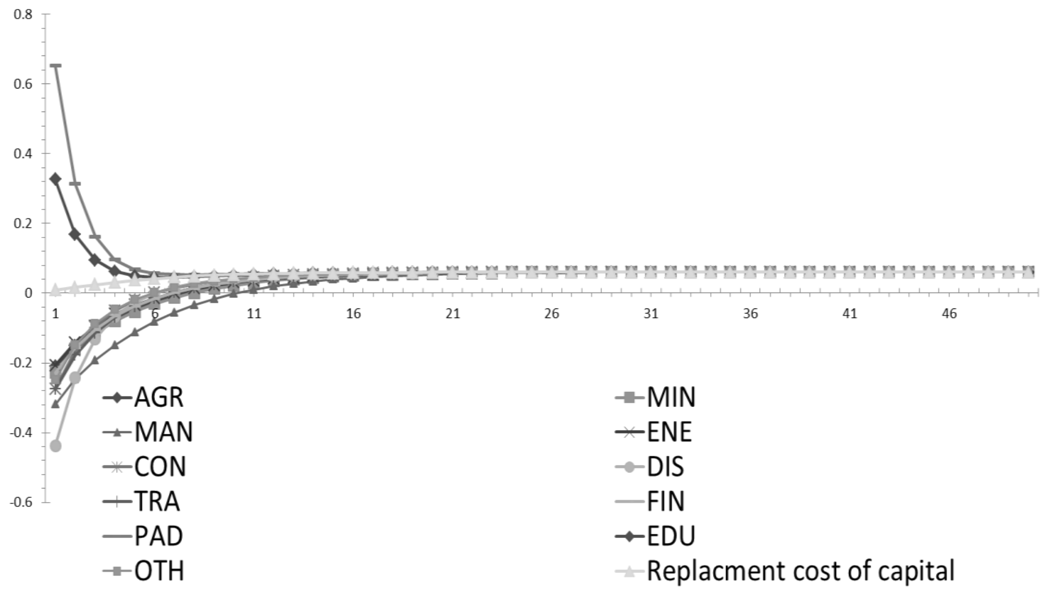
In our results (see Table 1, Scenario 2, RB), the response of an income tax-financed expansion in government spending is, both in the short and long-term, contractionary. This result contrasts with the externally financed disturbance where the distortionary effects of income tax are not present. In the short-run with fixed capacity, key variables such as output, consumption, employment and investment decline. The positive demand effect of an increase in government expenditure is more than totally offset by the adverse supply effect that an increase in taxes has on the bargained nominal wage and therefore competitiveness.

With the general contraction in activity the response of labour demand is also negative, reducing employment (-0.09%), increasing the unemployment rate (0.67%) and generating a reduction in the after tax real wage (-0.07%).

Over time population and capital adjustment come into play. The fall in the real after tax wage and the increase in unemployment encourage out-migration in this case, in contrast to where the public consumption was externally funded. Population continues to fall until the real after tax wage is restored and unemployment returns to its initial steady-state position. The increase in nominal pre-tax wage increases the production cost of labour reducing profit expectations. Therefore, negative investments exacerbate the direct and negative wealth effect due to a cut in individual resources, which implies a further fall in output.

Figure 2

Shadow price and replacement cost of capital. Scenario 2



Turning to a sectoral analysis, we see that only Public administration (PAD) and Education (EDU) exhibit positive change in activity, in the long run. The intensity of government purchases (in the benchmark data) is more marked in PAD and EDU than other sectors, so that, the positive demand effect in these sectors is able to produce capital expansion. However, this is insufficient to counteract the general contractionary effect in all of the other sectors. Figure 2 shows the evolution of the real shadow price of capital for all sectors. Note that only for PAD and EDU the shadow price of capital is higher than the replacement cost of capital, thus stimulating investment with positive effect on output. However, the magnitude of the impact on these sectors is insufficient to produce an overall expansionary effect.

6.3. *The impact of a permanent increase in current government spending: imperfect substitution between private and public consumption.*

I obtain quite different results in Scenario 3 in which I account for effective consumption and the elasticity of substitution between private and public consumption (C and G) is set equal to 0.2 (the low elasticity case).

In the short run, a positive impact on output is accompanied by a rise in investment (0.56%) and consumption (0.77%). Indeed, by allowing for substitution between *C* and *G*, the increase in government purchases raises the marginal utility of consumption that counteracts the negative wealth effect, producing a general expansion in regional activity.

The replacement cost of capital is above its benchmark equilibrium (0.08%) because of capital constraints. The labour force is fixed, though labour demand rises because aggregate demand expands, reducing the unemployment rate (-1.70%) and, unlike the case of Scenario 2, the bargaining power of workers increases and so does the real wage (pre-tax, 0.43% and after-tax, 0.19%).

Over time the behaviour of both migration and investment allow total output to rise further. The rise in the real take home wage and the fall in the unemployment rate result in an increase in population. In turn, the growth in labour supply eases the pressure on the wage until the real post tax wage is restored to its original level. Capital stock expands, driven by increases in investment. The dynamic effect of fiscal policy on investment is very different from scenario 2. Here the demand side effect of government purchases is reinforced by an increase in the individual's marginal utility that increases consumption offsetting the adverse (supply) effects of an increase in taxation and real labour cost. So the crowding in effect upon private consumption acts as a (demand side) counterbalancing stimulus to profitability thereby raising investment demand and then capital stocks.

In the model, exports are price sensitive. The increase in regional prices generated by the demand shock, through a rise in the nominal wage, has an adverse effect on competitiveness. However, the contraction in RUK and ROW exports, in the short and long run are not enough to offset total output, because production is supported by domestic consumption that stimulates domestic output.

When the elasticity of substitution is set to a high value, as in Scenario 4, output, employment and consumption decline in the long run. The results are compatible to a degree with previous business cycle models. Here the positive demand-side effect of an increase in government purchases is unable to outweigh the adverse supply-side effects of an increase in taxation that is made worse by the decline in consumption. But, because G is valued, the reduction in C is less than in the base case Scenario 2. Indeed, in this scenario although government expenditure enters individuals' utility functions, the marginal utility of consumption is prevented from rising by the high degree of substitution between private and public consumption. Since nominal and real wages rise so as to restore the net of tax wage, Scottish population and employment fall below their initial steady-state values.

6.4. *The impact of a permanent increase in public investment.*

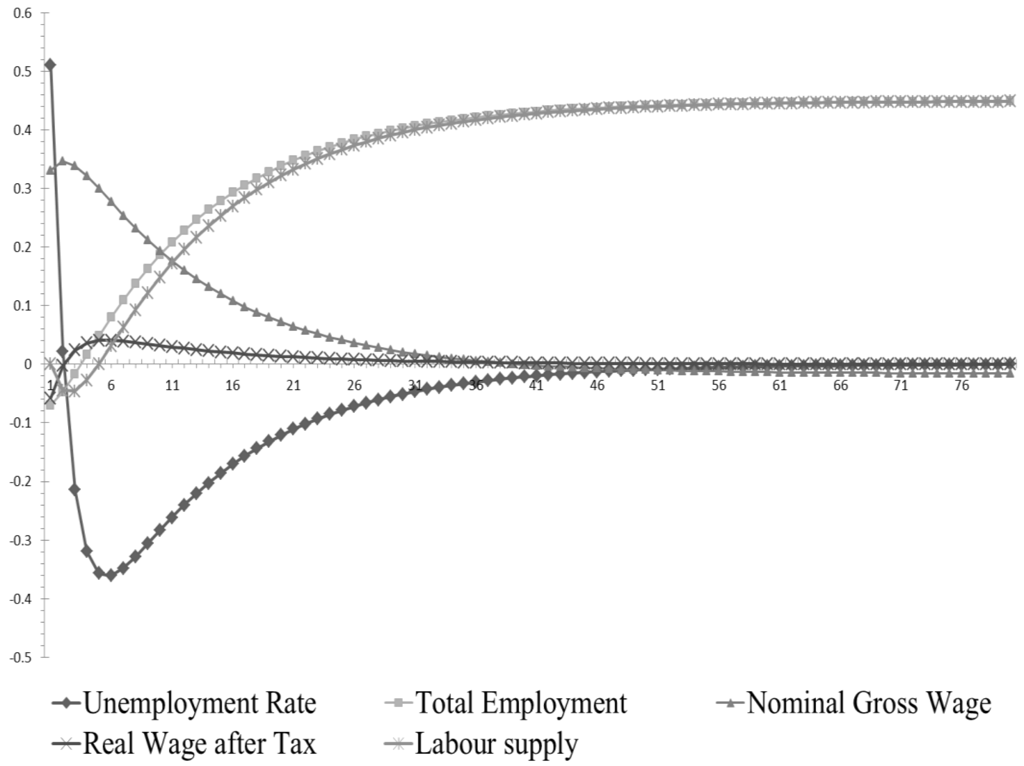
In this section, I analyse the effect of a 12.2% increase in public investment (which correspond to a 1.10% increase in government purchase of goods and services), again financed by an increase in income taxation. The results are reported in the Scenario 5 columns of Table 1.

In the short run, given the capacity constraint for private and public factors of production, the increase in public investment does not correspond to an expansion in the public capital stock by shifting the marginal product schedules, but can be seen as a simple stimulus to final demand. Therefore, in this time frame, we can distinguish two main simultaneous effects: the positive demand side effect associated with an increase in public investment and a negative effect of a resource cost related to an increase in taxation which also enlarges the wedge between before and after tax wage. Our results suggest a negative impact on employment and GDP but a positive impact on consumption and investment. In this simulation, therefore, the decline in regional activities does not correspond to a reduction in welfare. GDP declines by 0.03% as a result of a reduction in employment of 0.07% with respect to the base year. This is the result of an increase in the production cost of labour. Indeed, in the regional bargaining process, workers make adjustment in their pre-tax income after government expansion, which has implied a 1.94% increase in income tax. However, workers are unable to claim more, to maintain the same level of purchasing power, so the real wage after tax declines by 0.06%. With the fall in labour demand, unemployment rises, reducing the worker's bargaining power and so the real take home wage. Private investment expenditures are positively driven by the demand side of the economy. The expected future income related to the rise in commodities prices shifts up the real shadow price of capital reflecting profitability.

After the first period the situation changes significantly. In addition to the demand stimulus of an increase in investment and to a negative supply side effect of the distortionary tax, we also have an increase in the public capital stock that produces positive supply side effects. All capacity constraints are relaxed allowing public and private capital stock to accumulate over time while migration increases the working population. Turning to the dynamics in the labour market, (see Figure 3) only after the third period does total employment begin to rise. Wages are still high in the first three periods so that, we have a positive impact on labour input only at the beginning of period forth. The combined effect of a rise in the real wage after tax and reduction in unemployment rate encourage in-migration. Simultaneously, in-migration puts downward pressure on the real wage which gradually returns to its benchmark value. The labour market clears, at this point, where the change in employment equalizes the change in working population, and consequently the unemployment rate comes to rest at its original position.

Figure 3

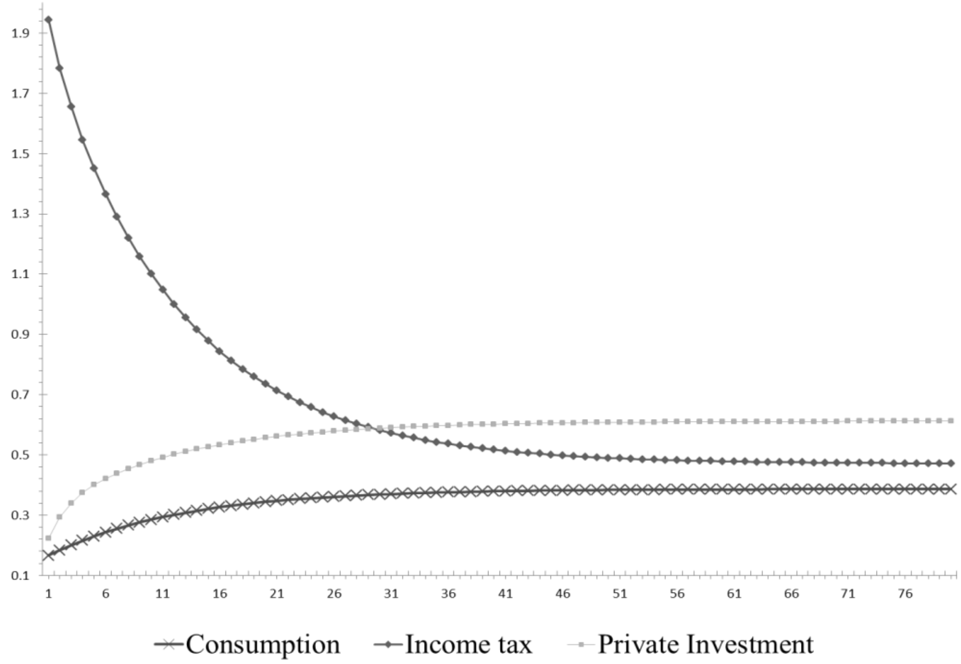
Labour market. Scenario 5



From inspection of Figure 4 we can see that consumption increases relative to the initial steady-state, although the average income tax rate is above its initial equilibrium. This reflects the important impact of the public capital stock: it produces a positive supply-side multiplier, by which increases in capital expenditure and tax rates induce a rise in output that in turn does not require additional increases in tax rates. As we can see from the chart the change in the average tax rate is positive but its magnitude decreases period by period coming to rest gradually at 0.47%. This is not an unexpected result since even in the very short-run we were able to see that the output effect of an increased public capital stock is able to offset the adverse resource cost effect of taxation. In other words, given the nature of public capital stock, its accumulation acts as an induced structural change that encourages private factors on the supply side of the economy, which ultimately more than totally mitigates the the distortionary cost of taxation.

Figure 4

Consumption, Investment and Income tax evolution. Scenario 5



The representative agent increases investment since the accumulation of public capital stock stimulates a strong rise in the marginal product of capital. Furthermore, the increase in private capital stock puts downward pressure on the capital rental rate, producing a system wide efficiency stimulus lowering commodity prices, which in turn puts downward pressure on the replacement cost of capital relative to the change of the shadow price of capital, so that Tobin's q moves procyclically, ultimately encouraging additional investment.

In the long-run, where all factors of production are fully adjusted, private investment increases by 0.61%, which is different from the percentage increase in output, implying that, the capital coefficient is not the same as the initial steady-state. Consumption and employment rise by 0.38% and 0.50% respectively.

The short-run results obtained here share similar features with the short-term outcomes of Scenario 2, our base case scenario, where I run an increase in government expenditure where there is assumed to be no direct effect of government expenditure on the marginal utility of private consumers. In both cases, the experiment is configured as a demand side shock of the same magnitude. So, *ceteris paribus*, we would expect the same short-run outcome as the base case, where the demand side effect is not able to offset the negative adverse supply side effect of the increase in taxation. However, this expectation is not fulfilled, most obviously because consumption and investment are forward looking with rational expectations.

In Figure 5, I show the evolution of consumption and investment for the forward looking (FL) and myopic case (MYP). In the myopic case initially consumption and investment, are below the original steady-state level and only when public capital expands does investment increase while for consumption it takes 6 periods to achieve a positive proportionate change. Of course, consumption and investment in both models finally converge to the same steady-state equilibrium. In the new steady-state, as intuitively we would expect, regardless of dynamic structure, both myopic and forward looking model must reach the same long-run equilibrium[33].

The main difference between the myopic and forward looking cases is in the adjustment towards the new steady-state. Consumption in the myopic model is determined, period by period, by current household income. This decreases in the initial periods because nominal wages fall and the income from physical assets dramatically decline. Private capital initially falls as a result of disinvestment generated by the falling capital rental rate.

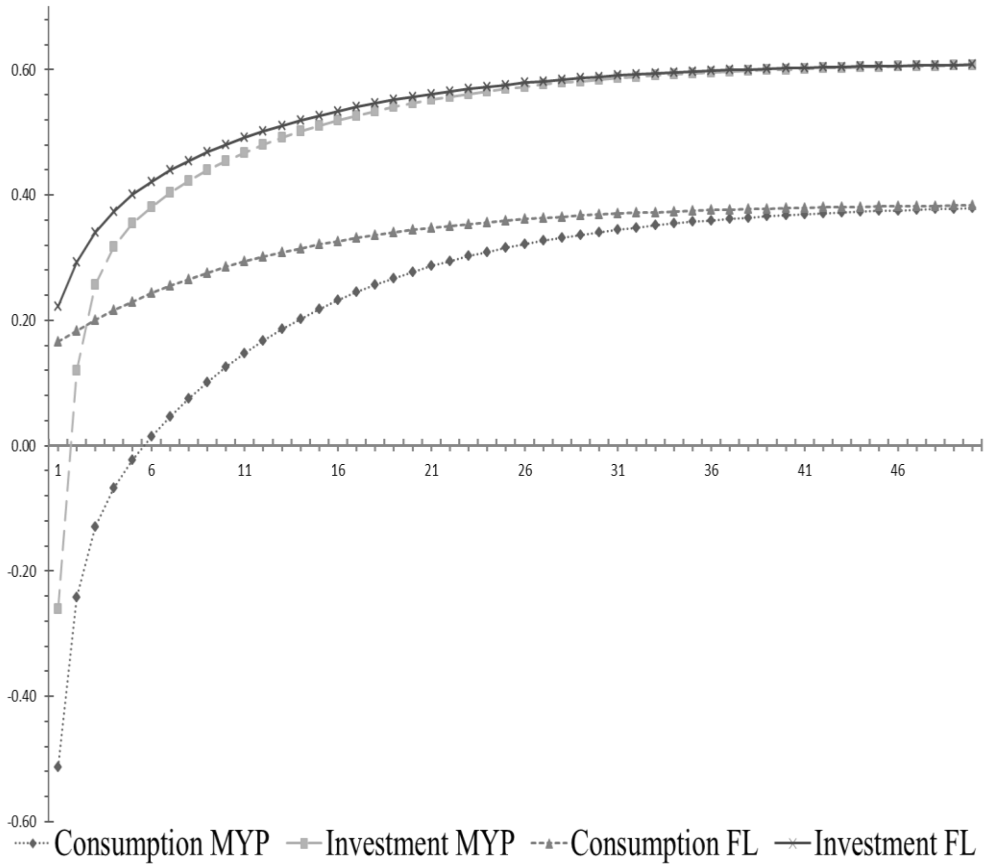
In the forward looking model, consumers base consumption decisions on expected future income and in the dynamic path there is no fixed link between consumption

[33] This particular outcome has not always been recognised in CGE models; see Chapter 2.

and current income. Investment is determined by profit expectations which are stimulated by the amplification effect of the increase in public capital stock. So, consumers and producers expect, from the outset, a positive stimulus due to the output effect that arises when public capital accumulates over time, as discussed above.

Figure 5

Myopic vs. forward looking: private consumption and investment. Scenario 5



6.5. *A simultaneous increase in current and capital government expenditure*

I run the simulation by setting the congestion parameter equal to 0.5 and assuming perfect substitution between private and public consumption ($\varepsilon \to \infty$).Results for the short-run and long-run are reported in the last columns of Table 1, labelled Scenario

6. In these circumstances given that the percentage increase of government expenditure is very close to the base case scenario the capacity of public capital to overwhelm the adverse supply side effect typically encountered in Scenario 2 does not arise in the short-run, but a partial offsetting occurs in the long-run where all factors of production completely adjust allowing for a supply side response of private factors and an amplification effect due to the expansion in public capital stock.

Note that in this case, in contrast to Scenario 2, the balanced-budget output and employment multiplier are positive both in the short and long run. Initially, as explained previously, government investment works like basic government purchases, labour input increases slightly, in turn lowering unemployment and rising real wages. There is also absorption of private resources reflected in the decline of private consumption and a slight decrease in private investment. Indeed, a permanent increase in government purchases (which is the dominant effect in this time frame) has a negative wealth effect on private individuals and despite the increase in employment and output, the drop in marginal product of private capital, due to a relatively dramatic increase in the replacement cost of capital, does not stimulate additional demand side expansionary effects and furthermore the fixed capacity prevents potential multiplier effects, so the effect is a decline in private investment. The drain of private resources is only temporary as far as investment is concerned. In fact, during the transition path one more effect comes into play, which is, however, not able wholly to counteract the negative wealth effect of an increase in government purchase on private consumption. But the accumulation of public capital, although adjusted for congestion, has a positive impact on private investment. In the long-run investment is 0.03% above its initial steady-state but consumption still remains crowded out coming to rest at 0.22% below its benchmark value.

It is interesting to analyse the impact of relaxing the constraint imposed by the UK Government on the split between capital and current expenditure. This allows the Scottish Government to choose the optimal share between the two categories of expenditure, to avoid crowding out effects on private resources. It turns out that in order to avoid the crowding out effect on private consumption the share of the budget spending allocated to current expenditure should be dropped to circa 60% (from the actual 88%) and consequently the share of public investment should increase from 12% to 40%. The level of shares necessary to avoid crowding out would change if, for example, we allow consumers to value current government expenditure.

If government purchases enter in the consumer's utility function, even with a high elasticity of substitution, (ε), private consumption goes up immediately. The parameter that governs the magnitude of the congestion effect has very little impact in this case and even with $\eta = 1$ crowding out effects on consumption are still apparent.

7. Sensitivity analysis

7.1. *The sign of the balanced budget multiplier under a fixed nominal wage*

The results analysed in Section 6 are obtained under a regional bargaining function. Considering only the case of perfect substitution between private and public capital, I simulate, in a balanced budget framework, an increase in current government expenditure of 1.10%. So that, these results are directly comparable with the regional bargaining case whose results are summarized in the second column of table 1.

From the third column of Table 1, we can see that under a fixed nominal pre-tax wage, National Bargaining (NB), the sign of the balanced budget multiplier is sensitive to labour market assumptions. GRP, employment and investment increase in both short and long-runs contrary to the results obtained under regional bargaining. A characteristic of this simulation is not only a positive balanced budget multiplier in the short and long-run but also the long-run zero price changes with the unemployment rate below its benchmark.

With the before tax nominal wage fixed an increase in government expenditure reduces the after tax wage to below its base year value because of a resulting increase in taxation. The impact on the wage has the effect of stimulating investment and reducing consumption.

During the adjustment path, the stimulus for in-migration is driven mainly by a fall in the unemployment rate. Indeed, while the real wage has fallen the reduction in unemployment rate is enough to boost in-migration. Migration will rise until the fall in unemployment rate offsets the impact of decline in real consumption wage on migration flows.

It is worth noting the impact on competitiveness. In the short-run the crowding out of exports in the sheltered sectors and construction are the result of increased regional prices in these sectors where public spending is concentrated, but once prices adjust fully, in the new steady-state exports are unchanged in every sector[34].

7.2. *Congestion effects for public current spending*

In the preceding sections I have only accounted for the possibility of public spending being valued by consumers, and varied the elasticity of substitution between private and public consumption. Here, I assume that congestion also applies to public current spending. I show the impact of varying η for alternative values of ε. In Table 2, I report the long-run percentage change in private consumption resulting from changing the level of the elasticity of substitution ε from 0.2 to 2 and the level of congestion parameter that lies in the range 0.2 to 1. Since the model does not take into account natural population growth, only in-migration can increase population density that in turn reduces the public services available per worker. If consumers value positively high government expenditure this, on the one hand, has a positive effect on migration since, as we have seen in the preceding analysis, the real take home wage rises and the unemployment rate declines making migration possible, but on the other hand this would reduce the effectiveness of public services because these are subject to congestion.

[34] Clearly, we could adopt a wage function that exhibited a degree of nominal inflexibility in the short-run, but bargaining property in the long-run. This would be likely, *ceteris paribus*, to increase the probability of a positive balanced budget multiplier in the short-run.

For high levels of ε (ε=2) consumption declines for every η whilst increases with very low level of ε(0.2 and 0.8) although, η, that defines the effective level of current public expenditure is set to its low level (0.2). This analysis, in effect, suggests that, for a balanced budget fiscal expansion, the critical value here is the substitution elasticity between private and current public spending; the changes in value of the parameter η impact as to amplify the direction of the effect imposed by setting ε.

Table 2

The impact on consumption of an increase in current government expenditure. Long-run percentage change.

		ε			
		0.2	*0.8*	*1.4*	*2*
η	*0.20*	0.550	0.259	0.100	-0.001
	0.40	0.598	0.261	0.075	-0.042
	0.60	0.650	0.263	0.050	-0.086
	0.80	0.713	0.265	0.017	-0.140
	1.00	0.807	0.268	-0.030	-0.219

7.3. *Responses to different values of η and different ways of congesting public capital.*

In section 6, I assume that the effective level of public capital is crowded out with increasing working population and private capital stock, for $\eta = 0.5$. However, we know that for a given congestion specification (as specified in Eq. (9)) by increasing η we reduce the magnitude of congestion while simultaneously increasing the productivity of public capital. Furthermore, since other formulations of congestion are possible the effective level of public capital might also be congested in different ways. Here, I study the short-run and long-run responses of key economic variables under different levels of the crowding out parameter η and alternative specifications of congestion. I report results in Table 3.

Table 3

The impact of an increase in government capital expenditure. Simulation results of changing the congestion parameter of public capital stock using different congestion specifications.

Congestion	0.10		0.20		0.40		0.60		0.80		1.00	
	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR	SR	LR
GDP												
a)	-0.046	0.174	-0.042	0.304	-0.033	0.534	-0.024	0.766	-0.014	1.041	0.000	1.416
b)	-0.047	0.290	-0.043	0.414	-0.037	0.630	-0.021	0.843	-0.012	1.090	0.000	1.416
c)	-0.008	0.176	-0.010	0.613	-0.008	0.990	-0.006	1.180	-0.003	1.311	0.000	1.416
Consumption												
a)	-0.192	-0.131	-0.093	0.011	0.081	0.263	0.256	0.516	0.463	0.816	0.744	1.225
b)	-0.100	-0.003	-0.005	0.132	0.160	0.368	0.313	0.600	0.499	0.870	0.744	1.225
c)	-0.175	-0.128	0.149	0.349	0.428	0.760	0.569	0.968	0.666	1.111	0.744	1.225
Investment												
a)	-0.001	0.150	0.047	0.277	0.160	0.501	0.291	0.727	0.460	0.996	0.703	1.361
b)	-0.408	0.263	-0.543	0.384	-0.778	0.595	0.443	0.802	0.545	1.043	0.703	1.361
c)	-0.182	0.152	0.053	0.578	0.299	0.945	0.455	1.131	0.582	1.259	0.703	1.361

a) Public capital stock is congested by population and private capital stock
b) Public capital stock is congested by population
c) Public capital stock is congested by GDP per capita

I distinguish between three types of congestion specification of the same general form as in Eq. (9-10): a) is the one used in the analysis of the previous section; b) public capital stock is congested only by working population; and c) public capital stock is congested by GDP per capita.

For all three cases and for all levels of η (except $\eta = 1$) the change in output is negative in the short-run for the same reason seen above and is positive in the long-run. When $\eta = 1$, we get the highest impact since in this situation public capital is considered non rival and non- excludable. By increasing η the negative impact on the short-run level of output is reduced while in the long-run the positive impact on output rises. Of course these results were expected given that by raising the level of *publicness* of public capital the greater is the response of private factors to the stimulus to public investment. The supply side multiplier rises, increasing labour input and capital stock and simultaneously offsetting the adverse effect of additional taxation.

This result to some extent confirms previous analyses of public investment. For example in Baxter and King (1993), even with a low level of productivity of public capital the long-run effect of public investment on output is positive.

Turning to consider consumption and investment, in the long-run even for the lowest level of η the proportionate changes in investment are positive whilst crowding out effects on consumption are present under specifications *a* and *c*. In the short-run, instead, consumption and investment fall in all three cases for the lowest level of η but consumption and investment begin to become positive for $\eta = 0.2$ respectively for the case *c* and *a*. In the short-run, because of fixed capital and labour, if the model is run without jumping variables the results in *a* and *b* are expected to be the same. In fact, running the model with myopic dynamic structure the inconsistency between *a* and *b* disappears.

8. Conclusions

In this paper I explore the likely impact of fiscal policy in a regional economy. The numerical CGE simulations suggest that there may be important potential welfare benefits to Scotland by endowing the Scottish parliament with greater tax varying powers.

The model employed shares some similarities with previous business cycle models, as far as the forward looking dynamic structure is concerned. The main difference is on wage setting and migration. The traditional intertemporal model is augmented with imperfectly competitive features in the labour market and a net-migration model (Layard *et al.*, 1991). Unlike the standard model that allows for substitution between consumption and leisure where the representative consumer chooses the quantity of labour to supply according to a flexible nominal wage, our model contains a wage bargaining function sensitive to the movement of the unemployment rate and labour supply increases through population due to in-migration.

I carry out a number of experiments; initially I investigate the response of an increase in current public purchase of goods allowing imperfect substitution between public and private consumption. Then, I consider the case of an increase in public investment and finally both shocks are performed simultaneously.

If private and public consumption are perfect substitutes ($\varepsilon \to \infty$) crowding out effects occur, whilst if the intra-temporal elasticity of substitution is sufficiently low (the case for $\varepsilon = 0.2$) an increase in government purchases is able to raise the marginal utility of consumption so as to outweigh the adverse effect of the increase in income tax rate.

The approach I have used here is, in some respects, unconventional if compared with the literature of fiscal federalism where models allow for fiscally induced migration and regional wage determination are directly affected by regional taxation. For instance, Lecca *et al*. (2010*b*) show the impact of a balanced budget fiscal expansion, in a model in which the local amenity generated by the government expenditure is allowed to influence wage bargaining behaviour and net-migration is specified in order to capture the effect on the migration decision of the locally financed amenity. Furthermore, public expenditure is valued by workers during the wage bargaining process making workers to some extent willing to give up part of their wages to obtain more public expenditure and not directly affecting the marginal utility of consumers as I do in the present paper.

In the present model instead the decision of migrants is independent of the productivity and the size of government spending, however these variables indirectly affect migration decisions through the expected wage and the probability of being employed. Moreover, fiscal policy is not a variable or a parameter that enters in the wage bargaining process. Here I use a different perspective according to which, if consumers value government expenditures as complements (or close) in their consumption, the impact of a balanced budget multiplier is positive and there is no crowding out effect on consumption and investment.

Furthermore, the different treatment of private and public consumption can be considered a novelty. To my knowledge nobody has attempt to compare the different impact generated by the two approaches.

The impact of an unanticipated public capital expenditure shock under perfect foresight, in the short and in the long-run, has a positive effect on private consumption and investment. The short-run dramatically diverges for the case in which agents have myopic expectations, under which circumstances there is complete crowding out.

Independently of the magnitude of congestion, in the long-run the balanced budget output and employment multipliers are positive, with private consumption and investment crowded-in. However, the short-run response can be sensitive to the congestion parameter. For very low level of congestion parameter, results suggest crowding out effects on consumption and investment whilst for a large level only with myopic agents does crowding out arise.

The analysis also has implications for the debate related to the breakdown between government current and capital expenditure. At present the Scottish Government does not have total control over the two types of expenditure. Fiscal autonomy without total discretionary, over the composition of spending might not achieve the desired effect as far as the Scottish Parliament is concerned. Furthermore, current constraints on the composition of public expenditure may prevent the regional government from achieving higher levels of output and employment.

The analysis is carried out in a single region. A natural extension of this analysis would be to develop an explicitly interregional analysis of fiscal policy effects. This would allow a fully analysis of regional fiscal reform in the UK. The results we would expect from a bi-regional Scotland-RUK model may be dramatically different, especially in the behaviour of wage and unemployment. Indeed, in the long-run the real wage and the unemployment rate should not return to their initial base year value as we have seen in these simulations.

A further extension would be to account for the potential impact of elements of public expenditure on migration decisions. In both cases we would also expect partial

Chapter 4

Rebound Effects from Increased Efficiency in the Use of Energy by UK Households

Keywords: Energy efficiency; Rebound; Households energy consumption; CGE models.

JEL codes: C68, D57, D58, Q41, Q43, Q48

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1. Introduction

The UK Government's 2007 Energy White Paper considers improved energy efficiency in the household sector a central means of achieving its energy targets of reducing the UK's carbon emissions by 60% by around 2050. According to the Department of Trade and Industry (2010), the domestic final consumption of energy has increased by 19 per cent since 1990 (and by 32 per cent since 1970). The 2004 UK Input-Output Table shows that the households directly account for about 30 per cent of all energy used in the UK. So, it is becoming extremely important to assess the extent to which policies aimed at increasing efficiency in household energy consumption produce the expected energy savings.

An energy efficiency improvement has the benefits of reducing the price of energy services. However, the extent to which such efficiency increase will be effective in reducing the consumption of energy (and thus the associated negative externalities, e.g., CO_2 emissions), is less clear.

In the energy economics literature, it is now accepted that the response to the introduction of new technologies aimed to save energy consumption is likely to be partially (or totally) offset by a reduction in the effective price of energy services[35]. This is what is known as the rebound effect, initially identified by Jevons (1865) and subsequently by Khazzoom (1980). Saunders (1992), in a neoclassical growth framework, emphasizes the possibility of an extreme situation, "backfire", where improvements in energy efficiency do not end up in any energy saving but actually increase the demand for energy[36]. After the work of Khazzoom (1980, 1987) a numbers of studies focus on the rebound effects, at the level of households (Dubin *et al*., 1986; Klein, 1985 and 1987; Nadel, 1993; Schwartz and Taylor, 1995; Greene *et al*., 1999; Waste, 2004; Frondel *et al*., 2008)[37].

The common characteristic of the literature listed above is that it is limited to the analysis of rebound at the micro level where only income and substitution effects can be captured (direct rebound). Furthermore, the magnitude of the rebound effect at the household level varies widely because the focus on the activity measured is substantially different in every study. That is, the focus is to consider the efficiency effect on one type of energy services such as personal transportation, residential space heating or cooling. The main result of all of these studies is that an increase in efficiency will end up in an overall reduction in energy consumption (Greening *et al*., 2000). That is rebound is the more common finding than backfire in the case of household energy efficiency.

There has been increasing interest in examining the nature and magnitude of rebound effects[38] in numerical general equilibrium models. However, to our knowledge, the work presented in Dufournaud *et al*., (1994) constitutes the only study that uses a CGE modelling framework to focus on rebounds effect from increased energy

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[35] For an extensive survey one can see Brooks (2000), Greening *et al* (2000) and Dimitropoulos (2007).

[36] This is also known as the Khazzoom-Brookes Postulate.

[37] An extensive summary of the extent of rebound on household consumption for several types of energy services can be found in Greening *et al*, (2000).

[38] A comprehensive review of computable general equilibrium models used to study energy rebound effect can be found in Dimitropoulos (2007).

efficiency in the household sector. This study analyses the impact of increasing efficiency in wood stoves in the household sector of Sudan.

A number of authors have examined the impacts of increased energy efficiency within the production side of the economy using CGE models (Semboja, 1994; Grepperud and Rasmussen, 2004; Glomsrød and Taojuan, 2005; Hanley *et al*., 2006 and 2009; Allan *et al*., 2007; Turner, 2009). For instance, the works of Allan *et al*. (2007) and Turner (2009) for the UK, and Anson and Turner (2009) and Hanley *et al*. (2006; 2009) for Scotland evaluate the impact of an increase in energy efficiency in the industrial use of energy. The characteristic of this shock is such that the increase in efficiency introduces a positive supply-side disturbance, whose primary effect is to raise production efficiency, particularly in energy intensive sectors. The efficiency gains stimulate economic activity through downward pressure on the prices, including the price of energy output since the energy supply sector itself is a typically energy intensive.

However a completely different outcome would be observed if the energy efficiency improvement took place in the household sector[39]. The expected results of an increase in energy efficiency in the UK households sector would be a clear example of a simple demand-side shock where households take all prices as given and the supply side effects are thus neglected.

In this paper, I study the economy-wide impacts of increased energy efficiency in the household sector, with particular attention to the conditions under which rebound (or backfire) effects may occur. I apply an intertemporal computable general equilibrium (CGE) modelling framework for the United Kingdom (UK).

[39] In the model outlined below I consider the household sector as a simple component of the final demand for goods and services. That is to say, that I'm abstracting from the case in which households are involved in the production of final goods and services through transformation of purchased intermediate commodities. Moreover, I do not consider the case in which households generate energy from their activity by for instance gathering firewood, as in the study of Dufournaud et al, (1994). This may be appropriate for an underdeveloped country, but in the context of the UK economy, it seems reasonable to consider households as a consumer institution which acquires goods and services in the market economy.

In the model, forward looking expectations are incorporated for each of five household income groups (quintiles). Household consumption of energy and other goods and services respectively are modelled as imperfect substitutes, so that the magnitude of the rebound effect is governed by the elasticity of substitution between energy and non-energy goods. The expected energy saving in consumption should be higher the smaller the elasticity of substitution. This is because a lower elasticity reflects less sensitivity to relative price changes and reduces the substitution in favour of energy when its effective price falls. In this case, the efficiency effect would be expected to dominate over the substitution and income effects, so that there is a net decrease in energy use. However, where this elasticity is greater than one, the fall in the effective price of energy will generate a net increase in the household consumption of energy and backfire occurs. Thus, given that the elasticity of substitution between energy and non-energy in the household sector is a key parameter of our model, here I estimate it using a cross entropy method (Golan *et al*., 1996). This estimated elasticity is used in the model simulations to identify the impact of energy efficiency improvement in consumption.

In the initial set up, the consumer price index (*cpi*) is defined as a function of the price of energy plus non-energy commodities, measured in natural units. In this context, the impact of energy efficiency in household consumption is simply to shift demand between consumption goods and services. However, it is more appropriate to readjust the *cpi* by defining the price of energy in efficiency units[40]. This means that changes in efficiency will affect the real wage. Improved energy efficiency reduces the effective price energy, providing a source of improved competitiveness as the nominal wage falls for any given real wage.

I also investigate how alternative assumptions about consumers' time preferences affect the magnitude of both the household and economy-wide rebound. I contrast

[40] I make a distinction between energy as measured in natural units and energy measured in efficiency units. So that, the energy supply sector delivers energy in natural units, however, when an increase in efficiency arise, measuring energy in efficiency units better should reveals the energy performance. Similarly, we can distinguish between the price of energy in natural units and in efficiency units. See for detail, equations 6 and 7 in the proceeding of the paper.

the conventional time-separable lifetime utility specifications with the case where preferences over consumption exhibit habit formation. In doing so, I use a simple specification of habit persistence (as e.g. Boldrin *et al*., 2001) distinguishing between internal and external habit formation (Abel, 1990).

The paper is structured as follows. In the next section I outline the main equations of our modelling framework. Then in Section 3, I outline the method used to estimate the elasticity of substitution between energy and non-energy goods and services in the household sectors. In Sections 4, I draw the simulation strategy and Sections 5, 6 and 7 are dedicated to explaining different elements of the results. The paper ends with some sensitivity analysis in Section 8, followed by conclusions in Section 9.

2. Model description

In this paper I develop an intertemporal variant of the UKENVI CGE modelling framework, the energy-economy-environment version of the basic AMOS CGE framework initially developed by Harrigan *et al*. (1991)[41]. In contrast to previous applications of UKENVI (Allan *et al*., 2007 and Turner, 2009) here consumption and investment decisions reflect intertemporal optimization with perfect foresight.

The previous version of the UKENVI model incorporates agents with myopic expectation. Likewise the previous models showed in the previous chapters, AMOS has been updated in order to overcome the numerous critics CGE models based on backward-looking expectations have been subjected. A forward-looking dynamic structure has the advantage to choose a best allocation of resources in each period without abstracting from future periods. Furthermore, the CGE model become closer to the structure of a business cycle model with infinitely-live agents allowing to

[41] AMOS is an acronym for A micro-macro Model Of Scotland, deriving its name from the fact the framework was initially calibrated on Scottish data. AMOS is a flexible modelling framework, incorporating a wide range of possible model configurations, which can be calibrated for any small open regional or national economy for which an appropriate social accounting matrix (SAM) database exists.

introduces new theoretical approaches developed in the economic literature such as habit persistence that we would never be able to incorporate if agents were myopic.

Three domestic transactor groups are incorporated: households, corporations and government; 21 economic activities or sectors[42].

The Mathematical presentation of the model is mainly the same I have presented in Appendix A. However, in order to accommodate the new model features here I briefly present some of the new model characteristics with more details in Appendix C.

Consumer Preferences

The economy is inhabited by five lifetime earning groups of households. Each *H*-type household optimises its lifetime utility function of consumption, which takes the form:

$$U^{H} = \frac{1}{1-\sigma}\int_{0}^{\infty}\left[C_{h,t} - bC^{H}_{h,t-1}\right]^{1-\sigma} e^{\rho t}\,dt \qquad (1)$$

Where σ and ρ are respectively the constant elasticity of marginal utility and the constant rate of time preference. For $b > 0$, household preferences are characterized by some degree of habit persistence whilst if $b = 0$, we return to the conventional utility function. The utility function I adopt corresponds to the case where household's habit is related to its own past consumption, C_{t-1}. This is known in the literature as internal habit. The other common specification of habit preferences links the household's habit to the aggregate economy-wide past consumption, $\overline{\mathrm{C}}_{t-1}$ (external habit)[43]. With internal habit, a household's consumption depends on its own past consumption, so that the agent takes into account the effect of his current

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[42] See Appendix C Table C.2 for details about aggregation.

[43] Habit formation is introduced in the model as a simple specification of household's stock of habit bC_{t-1}. Here b is the degree of intensity of habit persistence. See Christiano and Fisher (1998), Abel (1990), Campbell and Cochrane (1999), Boldrin et al. (2001) and Smet and Wouters (2003) for a general discussion on different and more advanced specifications of habit formation.

consumption on his future utility. Thus positive change in consumption at time *t* lowers the marginal utility of consumption in the same period while increasing it at *t+1*. For the case of external habit or “catching up with the Joneses” (Abel, 1990) consumption of each household is affected by the average level of aggregate consumption ignoring the effects of their own current consumption on future consumption decisions.

The introduction of habit changes the composition of household consumption only in the short-run and in the transitional path towards the long-run equilibrium. In the new steady-state the model achieves the same equilibrium, with or without habit. Indeed, the presence of habit introduces a complementary relationship between consumption in two temporally contiguous time period, modifying as a results the speed of convergence between the time-separable utility model and the model with features of non-time separable preferences. We would expect greater consumption smoothing effects for non-time separable utility than for the conventional utility function, given that household with habit persistence would like to maintain the previous standard of living. With habit formation, households have an aversion to changing their consumption in response to a shock, meaning that consumption adjusts more gradually because of the increased desire to smooth the consumption path. The main difference between internal and external habit is that in the latter, habit is seen as an externality. An agent with external habit disregards the impact that his own current consumption produces on his future utility. For the case of internal habit the agent completely internalizes the effect of his present consumption decision on the future evolution of his level of expenditure.

The *H*-type household budget constraint is defined as follows:

$$W_{h,t}(1+r)=W_{h,t+1}+Y_{h,t} \tag{2}$$

Y is the net income available for consumption, *r* is the exogenous interest rate while *W* is the total wealth, which is defined in the model as the sum of the financial (*FW*) and non-financial wealth (*NFW*).[44]

The consumption bundle $C_{h,t}$ is defined intra-temporal as a CES combination over non-energy $CNE_{h,t}$ and energy goods $CE_{h,,t}$:

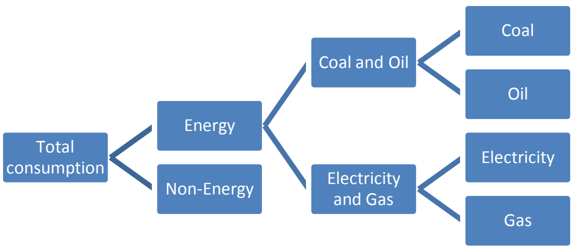
$$C_{h,t} = \left[\delta_h^E \cdot \left(AE_{h,t} \cdot CE_{h,t} \right)^{\frac{\varepsilon - 1}{\varepsilon}} + (1 - \delta_h^E) \cdot \left(ANE_{h,t} \cdot CNE_{h,t} \right)^{\frac{\varepsilon - 1}{\varepsilon}} \right]^{-\frac{\varepsilon}{\varepsilon - 1}} \quad (3)$$

Where ε is the intra-temporal substitution elasticity, $\delta_h^E \in (0,1)$ is the share parameter while $AE_{h,t}$ and $ANE_{h,t}$ respectively measure of technical progress for energy and non- energy.

Then the total level of consumption is divided in Energy and Non-Energy goods and services. The consumption of Energy is then a CES combination of Gas and Electricity from one hand and Oil and Coal to the other. Figure 1 below gives us a graphical representation of the consumption structure.

Figure 1

Consumption structure



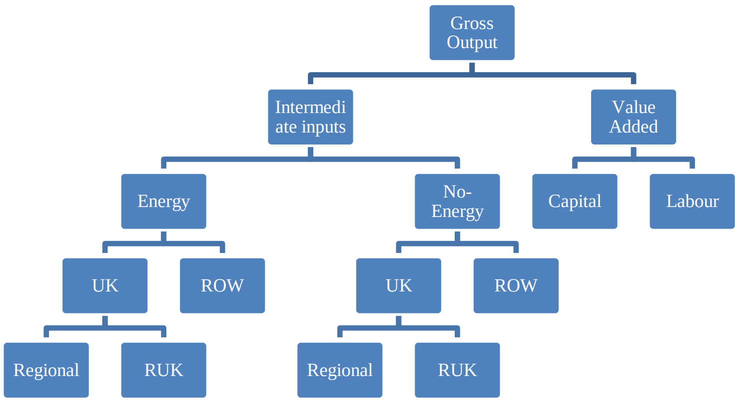
[44] See Chapter 2 for further details.

Then domestic and imported consumption of energy and non-energy goods are obtained via an Armington link (Armington, 1969) and are therefore relative-price sensitive.

Production. The model's production structure is illustrated in Figure 2, involving a hierarchy of CES relationships (with Leontief and Cobb-Douglas as a special case) between different inputs. Intermediate inputs (*VV*), labour (*L*) and capital (*K*) constitute the production inputs of the model. *L* and *K* are combined in a CES production function in order to produce value added, *Y* and VV is defined over Energy and Material[45] (or non-energy input) which can be produced locally or imported. These are considered as imperfect substitutes under the so called Armington assumption through a CES function. The Rest of UK (RUK) and the Rest of the World (ROW) are exogenous in the UKENVI model.

Figure 2

Production Structure for each sector *i*



Investment. The path of private investment is obtained by maximizing the present value of the firm's cash flow given by profit, less private investment expenditure, subject to the presence of adjustment cost (as in Chapter 2):

[45] The appropriate specification of the hierarchical structure of the KLEM (Capital, Labour, Energy and Material) production function is still under debate. A systematic sensitivity analysis of where energy should enter the production structure is in Lecca *et al*, (2011).

Labour forces in the present model are fixed[46] and wage setting is determined via a bargained real wage function that embodies the econometrically derived specification given in Layard *et al*. (1991**):**

$$\ln\left[\frac{w_t}{cpi_t}\right] = c - 0.068\ln\left[u_t\right] + 0.40\ln\left[\frac{w_{t-1}}{cpi_{t-1}}\right] \tag{4}$$

where *w, cpi* and *u* are the nominal wage after tax, the consumer price index and the unemployment rate respectively, and *c* is a parameter which is calibrated so as to replicate equilibrium in the base year.

To allow that change in efficiency produces improvement in the quality of energy services to be reflected in the real wage adjustment equation seen above, I modifying the *cpi* by expressing the price of energy in efficiency unit. To simplify the analysis, the *cpi* can be generally seen as a function of the commodities price:

$$cpi = cpi(p_{NE}, p_E) \quad cpi_{p_{NE}}, cpi_{p_E} \geq 0; \tag{5}$$

where p_{NE} is the price of non-energy goods and services and p_E is the price of energy services both measured in natural units (or physical units, e.g. Kwh). We can identify with λ an efficiency unit of energy and with γ the change in energy augmenting technical progress which is affecting the level of consumption per unit of physical energy consumed. So that:

$$\lambda = (1 + \gamma)C_E$$

In those simulations where I accommodate for the internalization of the efficiency in the wage bargaining process, I adjust *cpi* measuring the price of energy in efficiency units, as follows:

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[46] In other previous work on this topic, for the Scottish economy (Hanley *et al*, 2006 and 2009) labour force adjusts according to the econometrically parameterised net migration function reported in Layard *et al* (1991). In this case, given that the target economy is a Nation it seems plausible to assume constraints on the flow of migration at the national level in the UK. The introduction of change in population would require a more refined treatment of migration.

$$p_{\lambda} = \frac{p_E}{1+\gamma} < p_E \text{ for } \gamma > 0 \qquad (6)$$

$$cpi_{\lambda} = cpi(p_{NE}, p_E, \gamma) \qquad (7)$$

where p_{λ} is the price of energy measured in efficiency units. This means that with constant energy prices in natural units, p_E, an improvement in energy efficiency reduces the price of energy in terms of efficiency units, p_{λ}.

In this new specification positive efficiency shock put downward pressure on the *cpi* affecting the real wage equation, so that claims for higher real wages will be eased by the internalization of the energy efficiency in the local bargaining process.

3. Calibration and key parameters estimation

3.1. Model parameters

The model calibration process assumes the economy to be initially in steady-state equilibrium. The dataset is represented by a UK SAM which incorporates the 2004 Input Output table[47] and the classification of households in five income quintiles is in De Fence and Turner (2010).

I adopt the usual calibration method for the model that involves agents with perfect foresight[48]. For all sectors, trade elasticities are set equal to 2 (Gibson, 1990) whilst production elasticities are equal to 0.3 (Harris, 1989). The values of the adjustment cost parameter in the investment function, is assigned a value of 1.5. The interest rate is set to 0.04 (which is faced by producers, consumers and investors), the rate of

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[47] The core elements of the SAM database is the UK symmetric Input Output Table elaborated by the Fraser of Allander Institute.

http://www.strath.ac.uk/fraser/research/2004ukindustry-byindustryanalyticalinput-outputtables/. The Final SAM is in Appendix C, Table C.2.

[48] See Chapter 2 for a detailed discussion of the process of calibration of the intertemporal variant of the AMOS CGE modelling framework.

depreciation to 0.1 and with constant elasticity of marginal utility equal to 0.8. In the benchmark equilibrium the price of capital goods, *Pk*, is set to unity since the benchmark prices on the consumption side are set equal to one.

The degree of habit persistence (*b*) in consumption is set to 0.8 for both internal and external habit (see Banerjee and Batini, 2003; Batini *et al*., 2003)

3.2. Elasticity of substitution between energy and non-energy in the household sector

The value of the elasticity of substitution at the top of the consumption structure (as in Figure 1) is estimated below. Indeed, our purpose is not confined to a partial equilibrium analysis but it aims to obtain a measure of the potential magnitude of the economy-wide rebound effects by using the estimated elasticity into the CGE model.

The value of the other elasticity of substitution is derived for previous literature or best guess as summarized in Table 1 below.

Table 1

Parameter Values in the Household sector

Elasticity of substitution in household consumption	
Energy and non-energy	0.35 in the SR and 0.6 in the LR for all Household income groups
between non-energy goods and services	0.3
between coal and oil	0.3 for all Household income groups
between electricity and gas*	
HG1	0.44
HG2	0.44
HG3	0.33
HG4	0.2
HG5	0.2
*these elasticity are coming from the Baker et al 1989	

From Eq. (3) deriving the first order conditions, taking logs and rearranging, gives:

$$\ln\left[\frac{CNE_t}{CE_t}\right] = \beta_0 + \beta_1 \ln\left[\frac{P_{(E),t}}{P_{(NE),t}}\right] + \mu_t, \tag{8}$$

where μ is the (*iid*) error term. In this model, the coefficient of interest is β_1 which correspond to the elasticity of substitution between energy and material[49] in the household sector. In order to obtain an estimation for the long-run elasticity of substitution I estimate an autoregressive model of order one (AR(1)):

$$\ln\left[\frac{CNE_t}{CE_t}\right] = \beta_0 + \beta_1 \ln\left[\frac{P_{(E),t}}{P_{(NE),t}}\right] + \beta_2 \ln\left[\frac{CNE_{t-1}}{CE_{t-1}}\right] + \mu_t, \tag{9}$$

The short and long-run elasticities of substitution are given by β_1 and $\beta_1/(1-\beta_2)$ respectively.

Data on CE_t, $CNE_{,t}$ $P_{(E),t}$ and $P_{(NE),t}$ are required and are shown in Figure C.1 in Appendix C. I use annual data from 1989 to 2008. The energy index price is obtained from the Economic and Social Data Services (ESDS) database[50] while all the other are from the UK Office for National Statistical (ONS)[51].

The overall consumer price index is used as a proxy for the non-energy price index.

To estimate the model above I follow a conventional generalized maximum entropy (GME) estimation method (Golan *et al.*, 1996) which is a widely used technique to parameter estimation for CGE models (Jing *et al.*, 2003). I also perform OLS estimations for comparative purposes. A time trend is also introduced in the regression.

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[49] I will use materials and non-energy goods and services as synonymous.

[50] Economic and Social Data Services (ESDS). https://www.esds.ac.uk/.

[51] http://www.statistics.gov.uk.

Results of the parameter estimations and the associated confidence intervals are reported in Table 2. The GME confidence intervals are obtained through bootstrap method. Re-sampling has involved 5000 simulations. More details about GME estimation are given in Appendix C.

Table 2

OLS and GME estimations

				95% confidence interval			
Estimation	**OLS**	**GME**		**OLS**		**GME**	
	Est.	***Est.***		***low***	***high***	***low***	***high***
β_0	**0.850**	**0.848**		**0.41**	**1.29**	**0.31**	**1.14**
β_1	**0.346**	**0.345**		**0.02**	**0.67**	**0.12**	**0.64**
β_2	**0.433**	**0.435**		**0.15**	**0.72**	**0.12**	**0.75**
trend	**0.003**	**0.003**		**0.00**	**0.01**	**0.00**	**0.03**

For the OLS estimation the R^2=; *DW*:; Reset test F(2,33): []; Normality test: $\chi^2(2)$: []

According to the results summurized in Table 2 the GME and OLS estimations yield to identical results. The short and long-run estimates for ε are equal to 0.35 and 0.61 respectively.[52] By and large, our estimates are in line with previous empirical evidence for the UK households (see e.g. Baker and Blundell, 1991 and Baker *et al*., 1989) which predicts price elasticity generally less than one, meaning that backfire effects are unlikely to occur at least for the case of household rebound.

The 95% confidence interval for the elasticity of substitution derived from the GME and OLS estimations are 0.12 - 0.64, and 0.02 - 0.67, respectively. For both models the width of the confidence interval is small and the lower boundaries identify a Leontief relationship for the OLS estimation.

Given that the width of the confidence interval is smaller for the GME estimation, these estimates are then used to carry out a sensitivity analysis to determine the potential range of the households and economy-wide rebound effects (see Section 9).

[52] A comprehensive review of empirical estimates of direct rebound effects is in Sorrel *et al*, 2009.

The sample share of energy consumption in total consumption is 3%, which means that the price elasticity of energy demand is -0.345 and -0.61 in the short and long-run, respectively. These elasticities provide also a measure of the direct rebound effects of 33.47% in the short run and 59.05% in the long run[53].

4. Model solution and simulation strategy

In all simulations presented in this paper, I introduce a costless permanent step increase of 5% in energy efficiency in household consumption (i.e. *AE* in equation (3) is increased by 5%). I report results for two conceptual time periods, the short run and the long run, and the multi-period impact. The short-run impact corresponds to the first period of the simulation where capacity constraints are imposed. That is to say, the capital stock is fixed, not just in total but also its sectoral composition in this time interval. However, from the second period the capital stock adjusts through investment and depreciation. In the long-run the state variables of the model are subject to transversality conditions, so as to obtain a new steady-state.

Four scenarios can be distinguished: **1**, **2**, **3**, **4**. Only in Scenario **1**, the short-run and long-run impacts are obtained using the short-run and long-run household demand elasticity respectively. In all the others, I use only one elasticity of substitutions, namely the long-run one. The Scenario **3**, refer to the case where the model is run adjusting the *cpi*, according to EQ. (7) while habit persistence are introduced only in Scenario **4**.

In Table 3 I report the short and long-run impact on key macroeconomic variables in terms of the percentage change from the initial values[54]. I begin with scenario 1 where I impose the conventional utility function.

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[53] I consider the estimated elasticity of energy demand as a proxy of the direct rebound effects (Khazzoom, 1980). This is of course the easiest and more straightforward definition of direct rebound. However, this has also been criticized by Sorrell and Dimitropoulos, 2008 because subject to bias.

[54] I run the model for 20 periods. In period one I impose capacity constraint while in the last period steady-state condition applies. So, the first period corresponds to the short-run impact and the last period gives us the long run.

Table 3

Short run and long run impact on key macroeconomic variables of a costless 5% increase in energy efficiency in the Household sector. Percentage change from initial steady-state.

	Scenario 1		Scenario 2	Scenario 3
elasticity of substitution	0.35	0.61	0.61	0.61
	Short-run	Long-run	Short-run	Long-run
GRP Income measure	0.05	0.11	0.04	0.20
Consumer Price Index	0.08	0.03	0.07	-0.20
Unemployment Rate	-0.44	-0.60	-0.37	-1.12
Employment	0.08	0.11	0.06	0.20
Nominal Wage	0.13	0.10	0.11	-0.07
Real Wage	0.05	0.07	0.04	-0.05
Households Consumption	0.21	0.27	0.21	0.26
Investment	0.41	0.11	0.31	0.19
Non-Energy Output	0.08	0.12	0.06	0.21
	0.00	0.00	0.00	0.00
Household Rebound	45.47	68.13	70.26	67.64
Coal	42.33	67.99	68.46	67.41
Oil	42.74	68.02	68.71	67.44
Gas	49.72	68.10	72.56	67.78
Electricity	44.94	68.22	70.02	67.68
Economy-Wide Rebound	63.53	67.47	79.75	71.17
Energy Output				
Coal	-1.32	-0.74	-0.71	-0.70
Oil	-0.43	-0.22	-0.26	-0.11
Gas	-1.43	-0.86	-0.77	-0.83
Electricity	-1.11	-0.70	-0.59	-0.67
Investment				
Coal	-7.80	-0.74	-4.40	-0.70
Oil	-7.77	-0.22	-4.87	-0.11
Gas	-8.92	-0.86	-5.04	-0.83
Electricity	-4.13	-0.71	-2.30	-0.67
Export				
Coal	0.92	-0.09	0.44	0.07
Oil	-0.17	-0.12	-0.18	0.09
Gas	1.62	-0.07	0.83	0.05
Electricity	2.22	-0.06	1.15	0.05

In the first two columns I report the short-run and long-run impact of energy efficiency improvement in the household sectors using the corresponding estimated elasticities of substitutions: 0.35 and 0.61 respectively. The third column shows the short run impact of energy efficiency where the elasticity of substitution between Energy and Non-Energy is equal to 0.35. In the last column I report results for the case where energy efficiency has been internalized in the wage bargaining process by adjusting the *cpi*.

The econometric estimation suggests that household energy demand becomes more elastic over time. This implies that households take time to fully adjust their consumption to change in energy price. There are two possible processes operating here. The first is simply that there is some informational or other type of inertia that stops households from adjusting instantaneously. The second is that the adjustment in energy demand requires investment in the household's capital goods.

Neither of these processes is endogenously incorporated in the present model. Therefore, when I report short-run and long-run results, I use short-run and long-run household demand elasticity respectively[55]. However, when period by period results are shown, the long-run elasticities are used throughout. The uses of a single elasticity of substitution for all life time also simplify the analysis of the transition path making comparison more straightforward between the cases of habit persistence and no habit.

The appropriate use of the household demand elasticities estimated raises the issue of whether consumption behaviour adjusts straight away, through the implementation of new technology, or whether there is some inertia and/or delay in adjusting habitual behaviour. For example, in the case of more energy efficient appliance, such as a fridge, while it may take time for consumers to respond and actually invest in a new appliance, once it is purchased and installed, the energy efficiency improvement take

[55] These two time period shocks are not the results of a static simulation; these outcomes are obtained running the multi-period model imposing for all transition path one of the estimated elasticity of substitution.

place automatically and instantly. That is, the new appliance draws less electricity to maintain a given temperature than a less efficient version. Consequently, the consumer will observe and respond to a drop in the effective price of the energy type used to run the fridge – electricity – shortly thereafter (when they receive their bill) or even instantly (if the consumer has a smart meter installed) without having to take any further action themselves. In such circumstances, it is appropriate to use the long-run elasticity from the outset (even in the short-run), where the consumer is engaged in optimising behaviour.

On the other hand, if we take an example such as the installation of loft insulation, while this will reduce the amount of energy required to heat the consumer's home to a constant temperature, the consumer has to engage in two actions: first, having the loft insulation installed, then, second, adjusting the heating control (this is in contrast to the fridge example, where the consumer only has install the fridge). This second stage may involve time. The consumer will have to first understand how much they should reduce their use of energy input (e.g. how much time to have the heating turned on in a given 24 hour period) and then adjust their behaviour accordingly. This may involve the consumer receiving and interpreting several heating bills and (where relevant) smart meter readings, as well as changing their behaviour in terms of how they set their heating control.

In either case, rebound will not be triggered until the efficiency improvement has taken place (i.e. the installation of new technology) *and* (consequently) the effective price of the relevant energy type has fallen.

4.2. Rebound Calculation

The rebound effects on the household sector, R_{HH}, and the economy wide rebound effects, R, arises when the improvement in efficiency is partially (or totally) offset by an increase in energy consumption. They are defined as follows:

$$R_{HH} = \left[1 + \frac{\dot{E}_{HH}}{\gamma}\right] \cdot 100 \quad R = \left[1 + \frac{\dot{E}_T}{\alpha\gamma}\right] \cdot 100$$

where γ is the value of the energy efficiency improvement, $\dot{E}_{HH}$ and $\dot{E}_T$ are the percentage change variations of energy consumption respectively in the household sector and all domestic transactors, and α is the share of energy use directly affected[56].

R_{HH} (R) is negative if reduction in energy consumption is greater than the change in efficiency. While R_{HH} (or direct rebound) is just related to household energy consumption, the magnitude of the economy-wide rebound depends in actual fact on the impact that an improvement in energy efficiency in the household sector has not only in the final use of energy (final demand) but also use by the industrial sectors (intermediate demands).

5. Discussion of the results

5.1 Scenario 1

We begin with Scenario 1 where in the first two columns of Table 3 we report the short-run and long-run impact of energy efficiency improvement in the household sectors using the corresponding estimated elasticities of substitutions: 0.35 and 0.61 respectively.

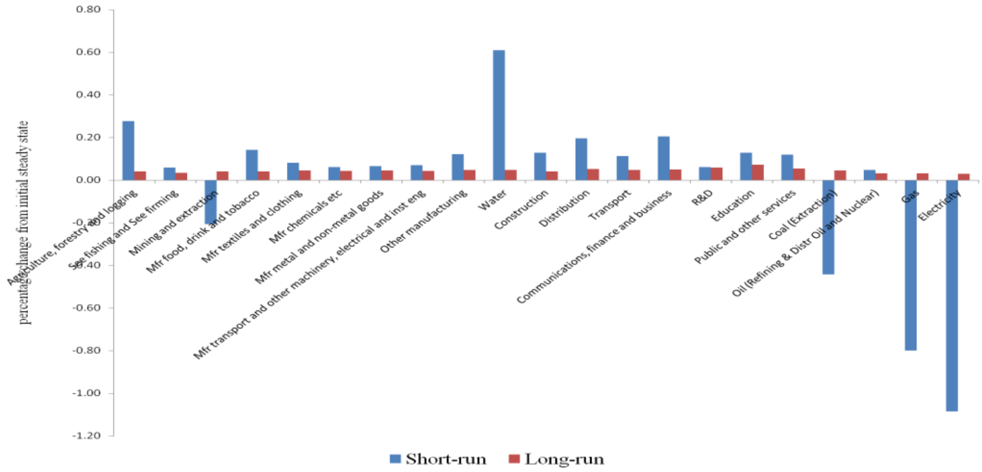
The relatively low sensitivity to price changes encourages consumption in commodities other than energy. The output of Energy for Coal, Oil, Gas and electicity fall (-1.32%, -0.43%, -1.43%, 1.11%), however the total Non-Energy output raise (0.08%). Although the demand for energy falls, the overall level of economic activity rises. Output, consumption and investment increase respectively by 0.05%, 0.21% and 0.41%. This stimulates labour demand, lowering the

[56] That is to say, the household energy use/the total domestic energy use, which includes the use of energy domestically produced and imported from the RUK and ROW.

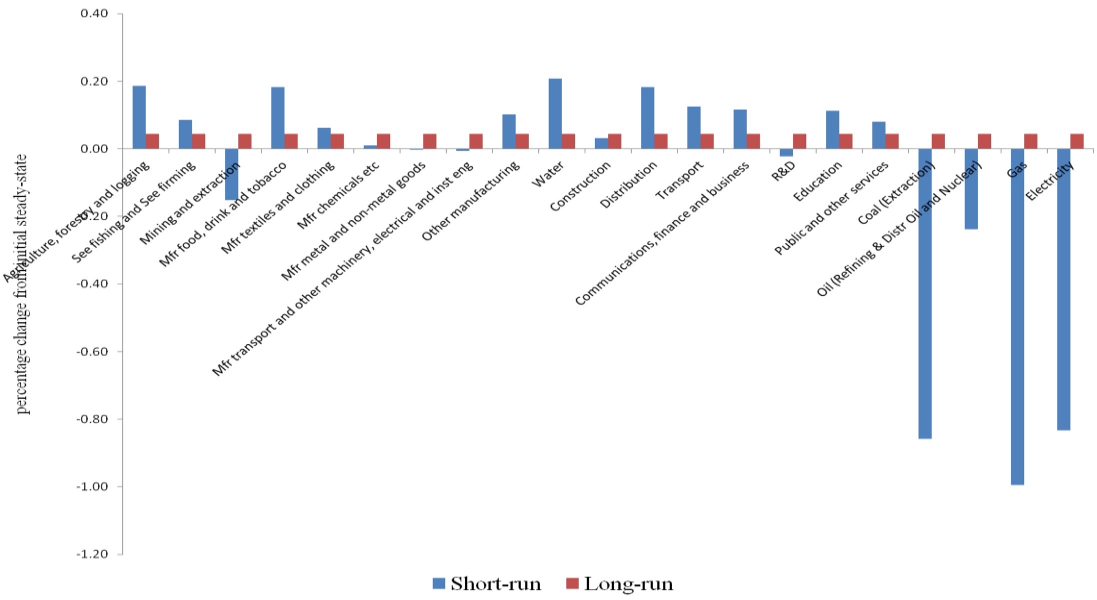
unemployment rate by 0.44% and increasing, as a consequence, the bargaining power of workers manifesting in a rise in the real wage of 0.05%.

Figure 3

a. Output price. Scenario 1



b. Shadow price of capital.



In the short-run the household demand for energy decrease for all type of energy sources. This is reflected in a total household rebound effect of 45.6%. The rebound effects is higher for Gas (49.7%) and lower for Coal (42.3%).

The reduction in energy consumption is partially offset by an increase in exports for Coal, Gas and Electricity generated by the increase in competitiveness reflected in a fall in the output price (see Figure 3a). Furthermore, as the demand for energy falls, so do Energy firms' profit expectations. So that the shadow price of capital declines in the energy sectors (see Figure 3b) in turn reducing investment in Coal, Oil, Gas and Electricity.

In the long-run, investments and outputs in the Energy sectors remain below their base year values. The GDP increases by 0.11%, with increases in total employment, investment and consumption of 0.11%, 0.11% and 0.27% respectively. The increase in household energy efficiency, and consequent substitution and income effects, has the effect of changing the composition of increased consumption in favour of non-energy goods and services. This puts upward pressure on the real wage and return on capital in non-energy sectors, which in turn increases in commodity prices and reduces competitiveness.

While there is a long-run increase in capital stock in non-energy sectors in response, decreased revenues in the Energy sectors lead to a contraction in their capital stock. Indeed in all energy sectors investment is declining. In order to restore equilibrium in the capital market, the decrease in the price of domestic Energy dissipates over time, allowing the shadow price of capital to rise to equilibrate with the replacement cost of capital (so that Tobin's q equals 1) in the long run. However, this also constrains the magnitude of the long-run rebound effect as found in the case of increased energy efficiency in production by Turner (2009).

However, the long-run increase in the price of Energy output, for all energy sectors and the overall price level (see e.g. the positive change in the CPI) contrasts with what we would expect in the case of increased efficiency in productive energy use. Here, the supply side of the economy is only indirectly affected by the efficiency improvement through changing demand for output and the disinvestment effect in the Energy sectors. In contrast, an increase in efficiency in the industrial use of energy would reduce the price of energy measured in efficiency units, which in turn tend to lower the price of output in all sectors, so that the source of economic growth is increased competitiveness.

In terms of the economy-wide rebound effect, the results in Table 3 show that, despite the constraining effects of disinvestment in the Energy sectors, the decrease in energy consumption by UK households and consumers is smaller in the long-run than in the short-run. This is reflected in the economy-wide rebound effect which increases from 63.5% in the short-run to 67.5% in the long-run. However, the contraction in the energy-intensive Energy supply sector, and associated reduction in energy use there, means that the rebound impacts in productive use of energy are more muted than in the household consumption sector, where general equilibrium impacts raise total household rebound to 45.5% in the short-run and 68.1% in the long-run. Note also that household energy consumption directly accounts for around a third of total domestic energy use, which means household energy use has a relatively large impact in identifying the economy-wide rebound effect.

In the next (second) scenario, on the other hand, where the long-run elasticity of substitution between household consumption of energy and non-energy goods and services is applied in the short-run also, the economy-wide rebound effect is stronger from the outset. Moreover, this is sufficient to bring about the result observed by Turner (2009) that economy-wide rebound effects (constrained by disinvestment) are bigger in the short-run than in the long-run, despite the presence of economic growth. We turn our attention to this scenario now.

5.2. Scenario 2.

The new short-run results in the third column of Table 3 demonstrate the impact of imposing the long-run elasticity of substitution between energy and non-energy goods and services in household consumption from the outset. The long-run outcome remains as observed in Scenario 1 (second column). However, with a greater elasticity (and, thus, stronger direct rebound) the short-run shift between energy and non-energy goods is reduced. This causes a more limited initial expansion in aggregate economic activity, but with a less dramatic short-run contraction in domestic Energy supply sector activities.

Despite smaller short-run decreases in revenue in the Energy sectors, in the presence of larger short-run rebound effects, the price response constraining long-run rebound is qualitatively the same as explained above. Figure 1 reports the percentage change in sector prices for the whole period of adjustment up to the attainment of the new steady state. Observe that the shock not only fails to generate a persistent price reduction in the Energy sectors but also the prices in all non-energy sectors rise during the entire transition path due to shifting and increasing demand. However, in the non-energy sectors prices do settle to some extent as positive investment relaxes supply constraints in these sectors.[57]

Given, that the physical price of domestically produced energy rises over the long-run (due to the disinvestment effect in energy supply), and despite some substitution in favour of imported energy, the stronger short-run rebound under Scenario 2 (68.5% for Coal, 68.7% for Oil, 72.6% for Gas and 70% for Electricity) is eroded so that household consumption of energy falls by slightly more in the long-run than in the short-run. This equates to an overall household rebound effect that is bigger in the short-run (70.3%) than the long-run (68.1%).

The energy price behaviour is the same analysed above. Figure 4 reports the percentage change in sector prices for the whole period of adjustment up to the attainment of the new steady state. The shock not only fails to generate a persistent price reduction in the energy sector (this price fall only in the first periods) but also the prices in all non-energy sectors rise during the entire transition path[58].

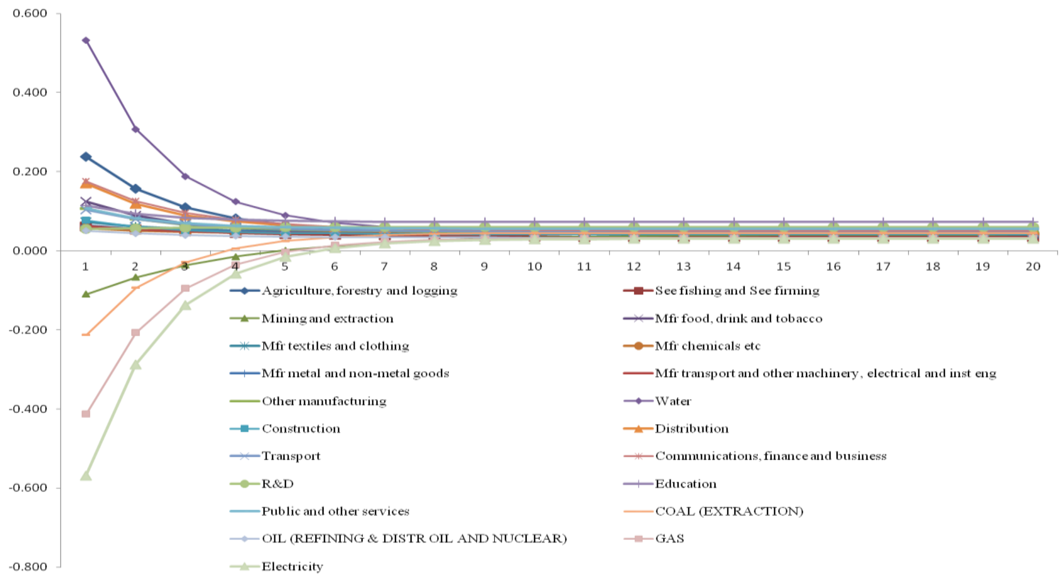
[57] Note that if labour supply were also allowed to adjust through migration using, the real wage would return to its pre-shock level and the general rise in prices would not be sustained.

[58] However this result only holds if the labour force is fixed. If labour supply adjust through migration using e.g., the net migration function commonly employed in AMOS (McGregor *et al*, 1996), in the long run the real wage and therefore also prices, return to their pre-shock level. That is to say, we should obtain typical Leontief results where only quantity changes but prices are invariant.

For an increase in efficiency in the use of energy in production Turner (2009) identifies the presence of disinvestment as a necessary but not sufficient condition for the rebound value to be greater in the short-run than in the long run[59]. Such "perverse" effects occur where the key elasticity parameter is the same for the entire transition path.

Figure 4

Commodity prices-% change from base year values



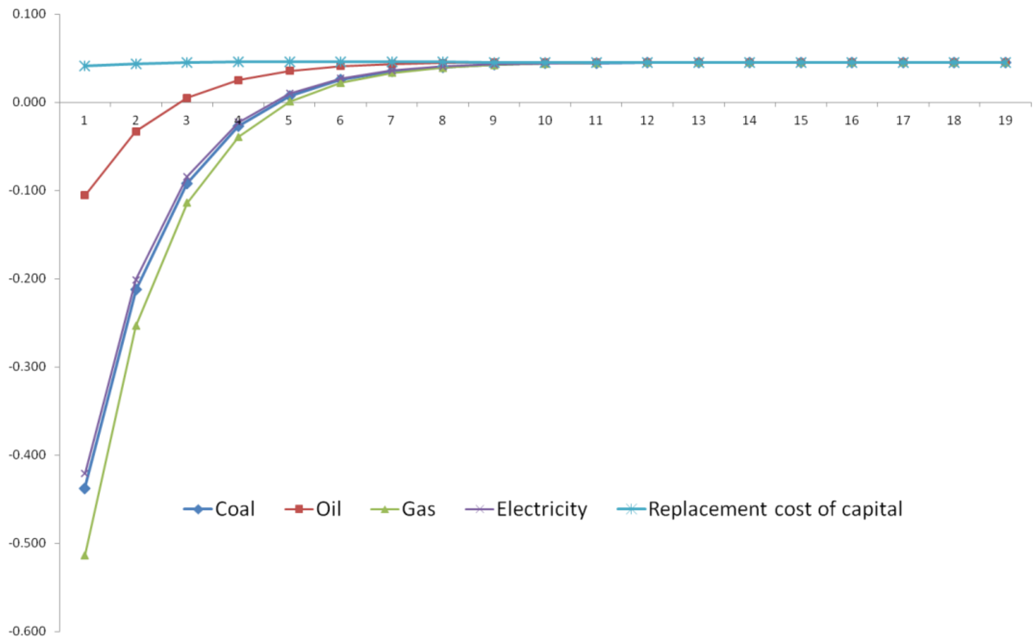
In Figure 5, I plot the shadow price of capital for each energy sectors and the replacement cost of capital. The curve of the shadow price of capital for the energy sectors is above the curve of the replacement cost of capital for the entire adjustment path (implying that Tobin's q<1). Ultimately, there is complete adjustment where the capital stock reaches the steady-state equilibrium. The trigger for the disinvestment effect can also be observed in the short-run results where the shadow price of capital falls by 0.23% in the UK energy sector. This is the trigger for shedding of capital

[59] Such a result contradicts the theoretical prediction of Saunders (2008), who argues that general equilibrium rebound effects will always be bigger in the long-run due to general expansion in economic activity when efficiency in the use of energy increases. However, as Turner (2009) explains, Saunders (2008) prediction is based on the theoretical model of Wei (2007), where the return on capital is assumed fixed and exogenous.

stock in the energy sector. The shadow price of capital falls because the initial contraction in demand for energy sector output, due to energy saving in the household sector (the pure efficiency effect) causes the price of this output to fall.

Figure 5

Disinvestment in Energy sector. Shadow prices of capital and Replacement cost of capital. % change from initial steady-state.



As in Turner (2009), it is the disinvestments effect, that constraint the long-run rebound effect. In our analysis, however, I find that the disinvestment is not the only element that limits the long-run expansionary effect making long-run rebound lower than the short-run. Loss in competitiveness in the energy sectors, which is partially driven by disinvestment effects, is another factor that constraints both the economy-wide and the household long run rebound effect. In Turner (2009) the analysis was confined to the supply side of the economy where energy efficiency occurs in the industrial use of energy. In that case competitiveness was stimulated by an increase in efficiency that in turn lowers the domestic price of energy and non-energy goods.

Indeed, in this analysis, both the economy-wide and household rebound effects are bigger in the short run than the long run when both the short-run and the long-run impact are obtained by using the same elasticity of substitution between energy and non-energy (in this case $\varepsilon_{LR} = 0.61$). But, the long run rebound is greater in the long-run than the short-run if the short-run impact is obtained using its own elasticity of substitution ($\varepsilon_{SR} = 0.35$). Although in both simulations we observe disinvestment in the energy sector, where the demand is more elastic in the long run, I obtain conventional results, where the short-run is lower than the long-run rebound. However, if the demand elasticity does not change over time, then if disinvestments occur, there will also be a larger short-run than long-run rebound. This finding, certainly hold in partial equilibrium analysis as shown in Allan *et al*., (2009) and in previous numerical general equilibrium analysis (Allan *et al*., 2006; Hanley *et al*., 2006, Turner, 2009).

The appropriate use of the elasticities of substitution makes the difference in the calculation of the rebound. I have calculated the impact of energy efficiency for two conceptual time frames and for the entire transition path. By and large it is widely accepted that for a one period (or temporary) shock, the short-run elasticity should be the more appropriate to use, given that individuals will be less responsive to price change when energy efficiency policies are introduced. However, in order to obtain the long-run impact, a greater level of price responsiveness is required. For a permanent shock, since the interest is to study the entire transition path towards a new long-run steady-state equilibrium, the long run elasticity is the appropriate one to use[60].

6. Results of energy efficiency for the case of adjusted *cpi*: Scenario 3

So far, the increase in energy efficiency in the household sector acts in the same way as change in tastes. This is because the real wage has been expressed as a function of the nominal wage and the consumer price index, *cpi*, which combines the price of energy plus non-energy commodities, measured in natural units. However, in

[60] A one period shock with long-run closures produce the same equilibrium of a permanent multi-period shock of the same magnitude.

defining the *cpi* it may be more appropriate to measure the composite energy price in efficiency units. This involves calculating the real wage as in Equations (7-8) above so that, in so far as improvements in energy efficiency reduce the energy price (measured in efficiency units), this will translate to a source of improved competitiveness as the nominal wage falls.

In this section, we repeat the simulation of a 5% increase in energy efficiency in household consumption. However, as in Scenario 2 I set the elasticity of substitution between energy and non-energy in household consumption to the long-run value of 0.61 for all periods.

In Figure 6 we compare the period by period adjustment of the *cpi* and nominal wage with that in the Scenario 2. We see that in the Scenario 2 both the *cpi* and the nominal wage rise and are maintained above their base year values. However, in the simulation where I account for the fall in the price of energy in efficiency units, both *cpi* and nominal wage fall and remain below the base year values. The fall in nominal wage reduces labour input costs to all production sectors, thereby offsetting the negative competitiveness effects of increased household demand. Over the long-run, Figure 7 shows that there is a net *decrease* in the price of output in all production sectors as the price of labour falls, with consequent impacts on local intermediate input prices. Thus in the last column of Table 3 we observe a greater positive impact on key macroeconomic variables such as GDP, employment and investment.

Nonetheless, as in the previous two scenarios, the reduction in the demand for energy services (measured in physical units) resulting from the increase in efficiency in household energy use leads to fall in the shadow price of capital such that the price reduction over the entire time interval causes disinvestment in the energy sectors. However, this is somewhat limited by what is effectively a positive supply shock when the efficiency improvement is reflected in household wage demands with the result that long-run rebound is larger relative to that observed in Scenarios 1. Moreover, while the smaller contraction in household energy use leads to a slightly larger total rebound effect there (67.6% relative to 68.1% in Scenarios 1 and 2), the wage effect has a much stronger impact on industrial energy use so that the overall economy-wide rebound effect grows to 71.2%.

Figure 6

CPI and nominal wage. Comparison between Scenario 2 and Scenario 3

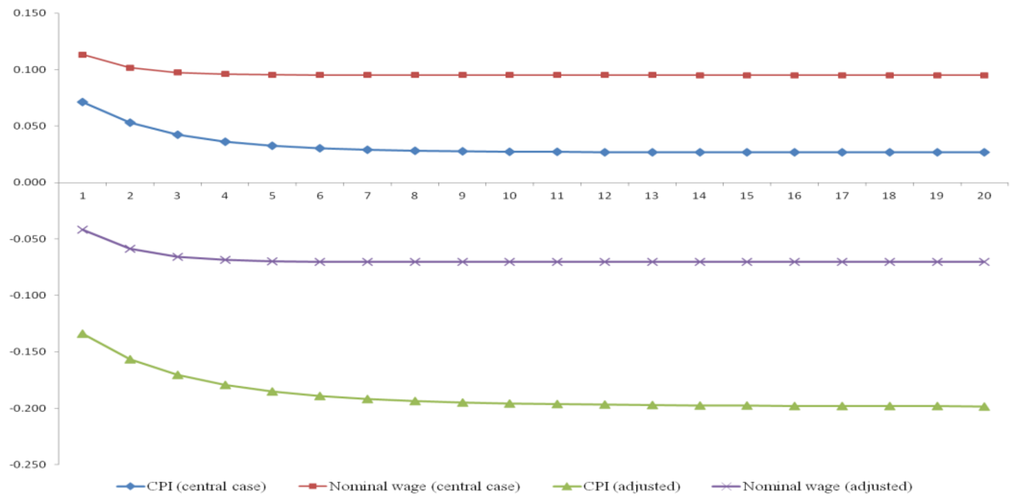
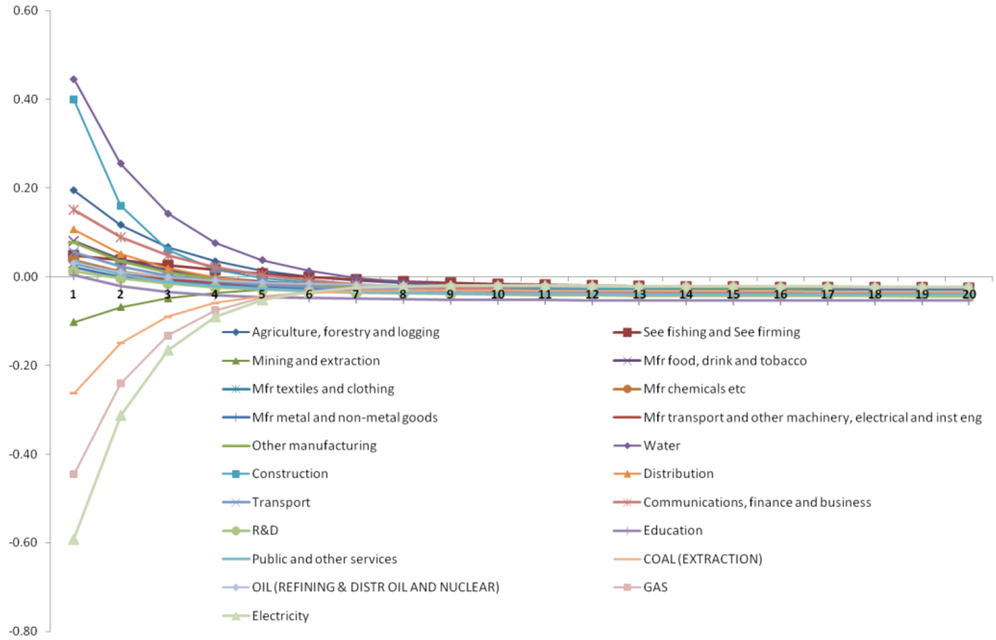


Figure 7

Commodity prices-Adjusted CPI-% change from base year values



7. Results of modelling agents with habit formation: Scenario 4

In this section, I examine whether the introduction of habit persistence in consumption is sufficient to change the composition of household consumption in order to modify the extent of household rebound. Furthermore, in considering different specifications of habit (internal and external) I consider whether qualitative and quantitative differences arise with respect to the Scenario 2 and analyzing how habit formation influences the impact of an increase in energy efficiency on the evolution of the economy.

For all three models I make the assumption that within the periods the shape of the relationship between energy and non-energy goods and services is defined by the same elasticity of substitution, ε=0.61, as in Scenario2, for the entire transition path. This simplifies the analysis significantly. The application of the short-run elasticity for the first period only quantitatively impacts on the results, but as the sensitivity analysis confirms, the qualitative results emphasized in this paper, especially in this section, depend only on the specification adopted for the utility function.

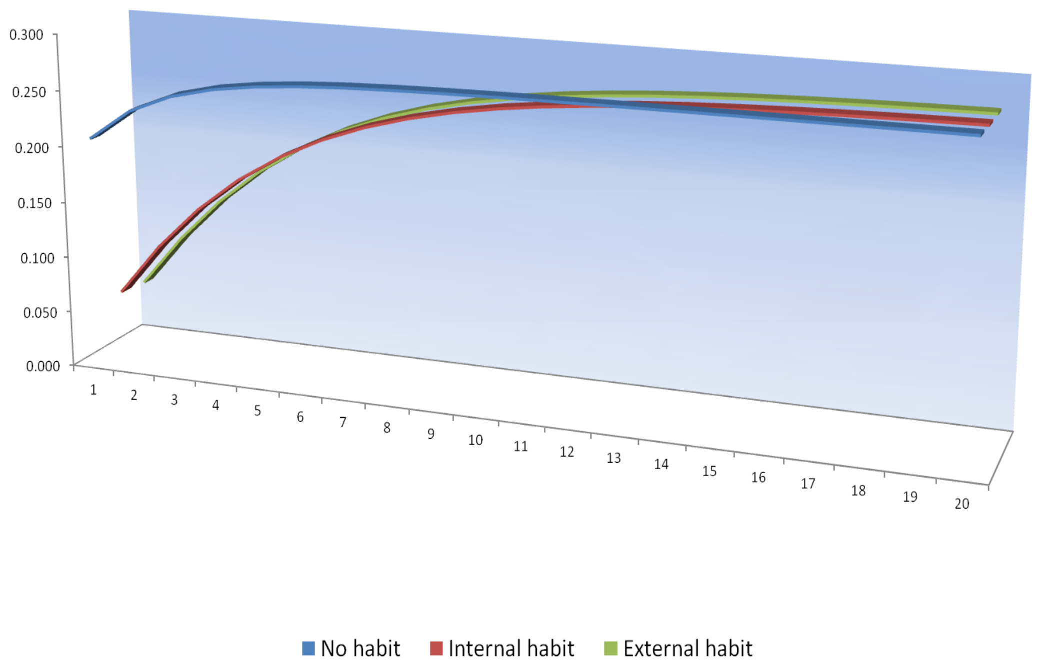
In Figure 8, I report the period by period percentage changes of aggregate consumption for the central case model (no habit) and the cases with internal and external habit formation. We see that consumption growth is different during the transition path but ultimately all three curves come to rest at the same steady-state equilibrium. The differences are all in the adjustment path towards the long-run equilibrium. From the chart, it is clear that households having conventional preferences enjoy bigger short-run consumption increases than those having non-time separable preferences. This is because with habit preferences, consumers try to maintain their previous standard of living and in that case after the increase in efficiency agents will substitute future for present consumption, by in this case, increasing saving.

For the case of external habit, and despite heterogeneity in the household sector, we see that the transition path is similar to that of internal habit. So, in the short run, in terms of aggregate consumption, an external or internal habit does not make significant differences. Aggregate consumption increases by 0.051% and 0.052%, with respect base year value, for internal and external habit respectively which are less than half if compared to the change for the case of no-habit.

One very small difference occurs between the two time non-separable model specifications. This is because with the external habit, each household's habit is determined by average consumption in the economy as a whole rather than by the average consumption of their own group. Thus a switch from internal to external habit formation does not make much impact on aggregate consumption. This point has also been made by Campbell and Cochrane (1999, pg. 245) where different habit specifications are analysed in order to identify asset price behaviour.

Figure 8

Period by period consumption change resulting from a costless 5% increase in energy efficiency in the Household sector.



The exogenous efficiency shock implies changes in the quantitative sectoral composition of household consumption when we switch from the no-habit to the case of habit persistence. The simulation results suggest that the household energy requirement is different for the three model specifications. Total energy saving in the household sector is 1.65% for the case of internal habit but rest to 1.68% when I impose the external habit. So, in the short-run the household rebound effects are bigger for the case of no-habit and lower for the case of external habit.

In the long run, and regardless of the agents' behaviours, energy consumption falls in each households group with upper income classes that save more energy than lower income households. Table 4 shows that rebound effects are in the order of 70.5% for the lowest income quintile and 67.1% for the highest one. This occurs because the population is fixed, the number of households remains unchanged, and the wage rate together with the price of energy does not change across households so that more energy-intensive households save proportionately less energy.

Table 4

Short run and long run household and economy-wide rebound resulting from a costless 5% increase in energy efficiency in the Household sector.

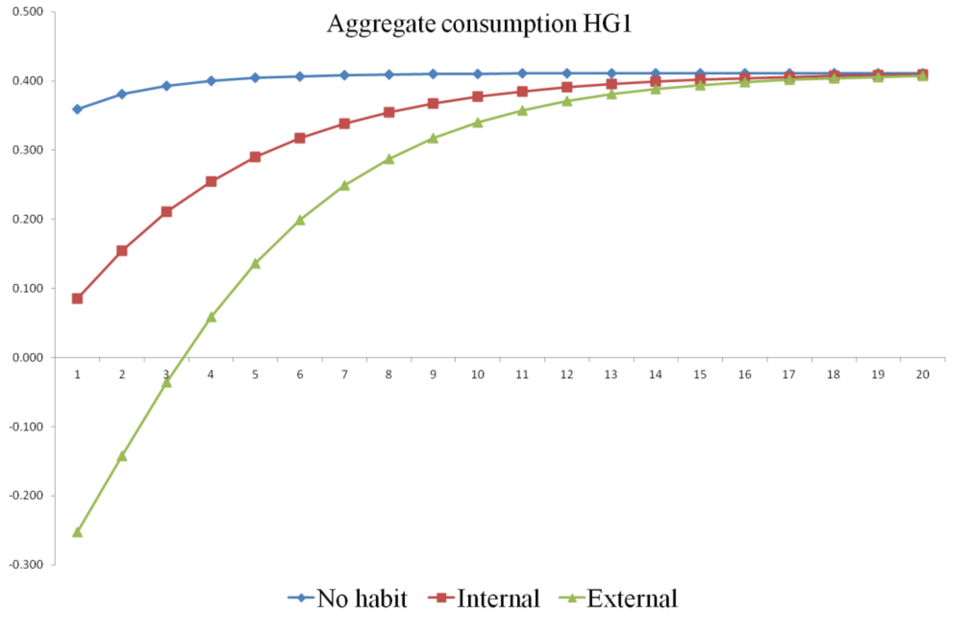
	Short-run impact						**Long-run**
	ε=0.35			**ε=0.61**			
	No-habit	Internal	External	No-habit	Internal	External	
Economy-wide rebound	63.53	61.93	61.34	79.75	78.19	77.67	67.47
HH rebound	45.47	42.18	41.45	70.26	67.02	66.38	68.13
HG1	48.47	42.98	35.95	73.09	67.78	61.23	70.50
HG2	46.74	42.56	40.42	71.44	67.38	65.36	69.08
HG3	45.47	42.22	42.04	70.25	67.06	66.91	68.08
HG4	44.62	41.96	42.66	69.45	66.80	67.52	67.46
HG5	44.04	41.75	43.18	68.91	66.60	68.05	67.07

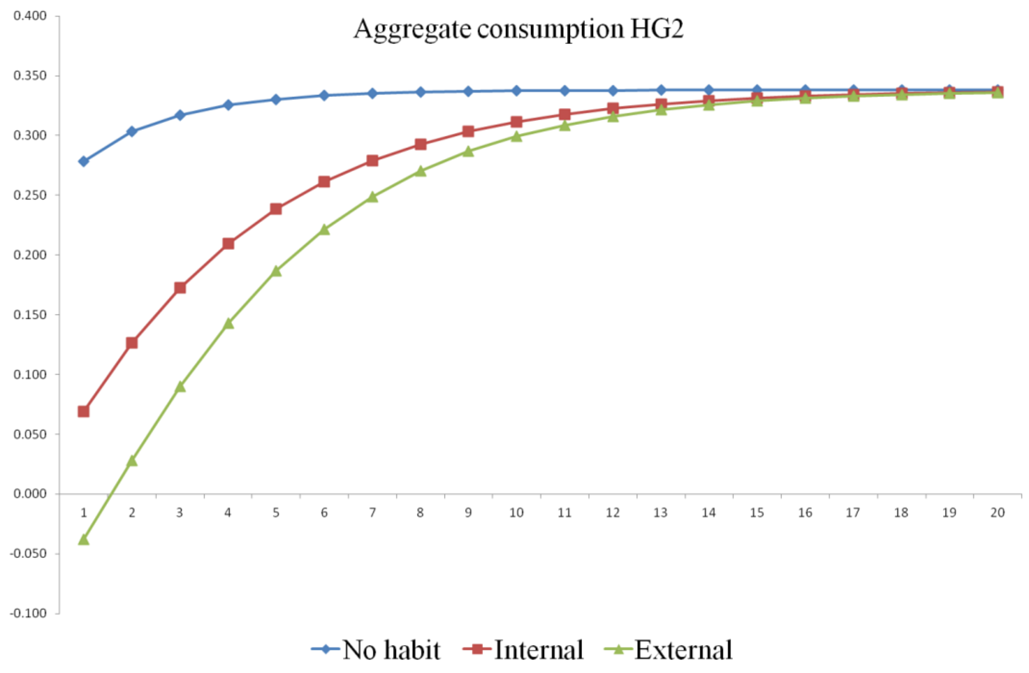
While in the long run the household rebound effect remains unchanged between the three different models, in the short run the greater consumption smoothing for the case of habit persistence produce differences in energy saving across households. Table 4 reveals that in the short run for the case of internal habit and conventionally determined household consumption, the energy saving for each group of households has the same long-run order, namely, household rebound effects are bigger for lower income households. However, this is not the case when agents have time non separable preferences in the form of external habit. Here rebound effects are higher for upper income quintiles: for the poorest household the rebound effect is 61.2% while for the richest one is 68.1%.

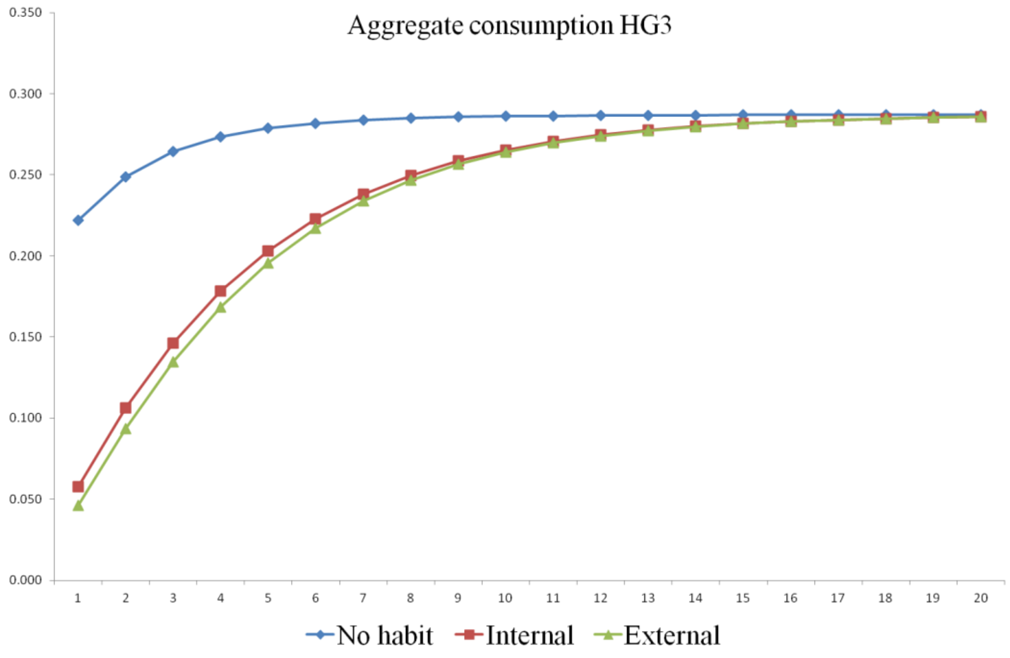
According to the model configuration, once each household makes intertemporal decisions of the aggregate level of consumption and saving, then within period they allocate consumption to energy and non-energy good and services. Since the elasticity of substitution, which defines the magnitude of the rebound, is the same across the board and for the three model specifications, it is the aggregate level of consumption that produces different magnitude for household rebound. For the case of external habit formation, households' current utility depends upon the average household's aggregate past consumption, rather than individual consumption. Thus, there will be some households whose level of consumption is below the average and other well positioned above the average. Now if we look at the Figure 9 we see that the extent to which household smooth consumption is greater for a group of household with level of consumption below the average household consumption (e.g. the poorest one) and vice versa. The level of aggregate consumption for the first and second quintile is even negative, implying that they are saving a bit more than other households. Poorer households are consuming less overall, then they will consume less energy as well. This implies that, in the short run, and under external habit, the income effect is proportionately lower for poorer household. This also means that, contrary to the internal and no habit case the reference benchmark energy-intensities do not play a significant role in defining consumers' decisions.

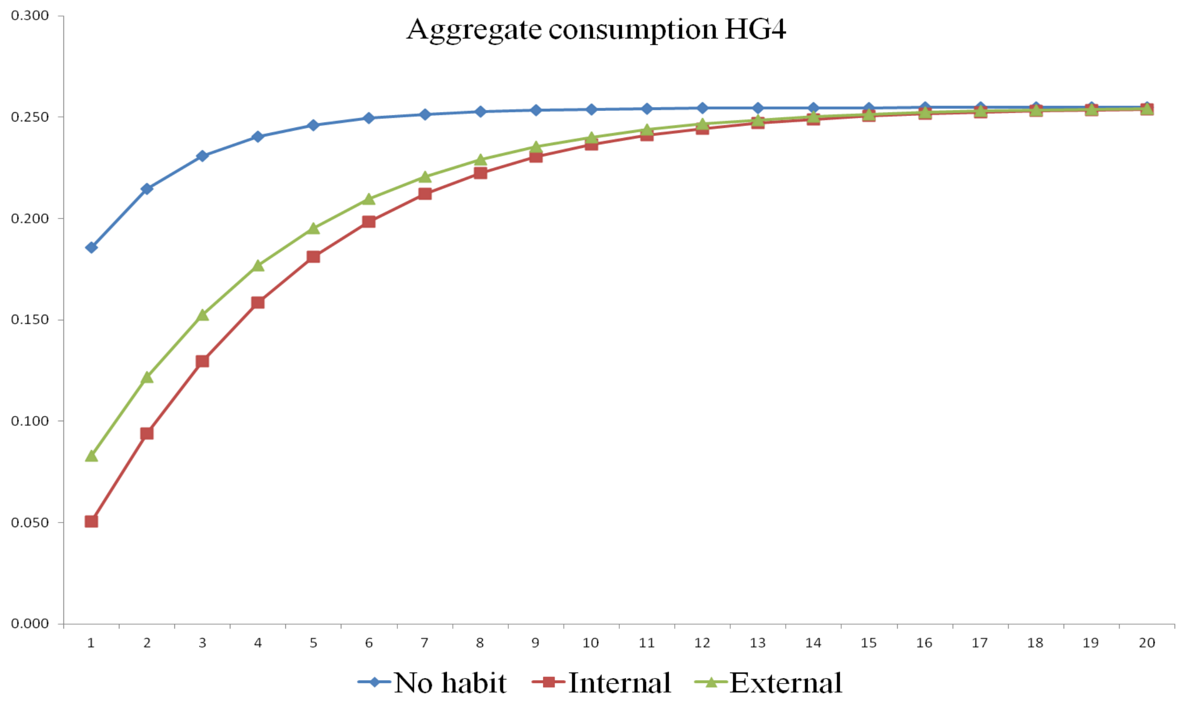
Figure 9

Period by period consumption change for each 5 income quintile and for the three specification of the utility function






Aggregate consumption HG3
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
No habit
Internal
External


Aggregate consumption HG4
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
No habit
Internal
External

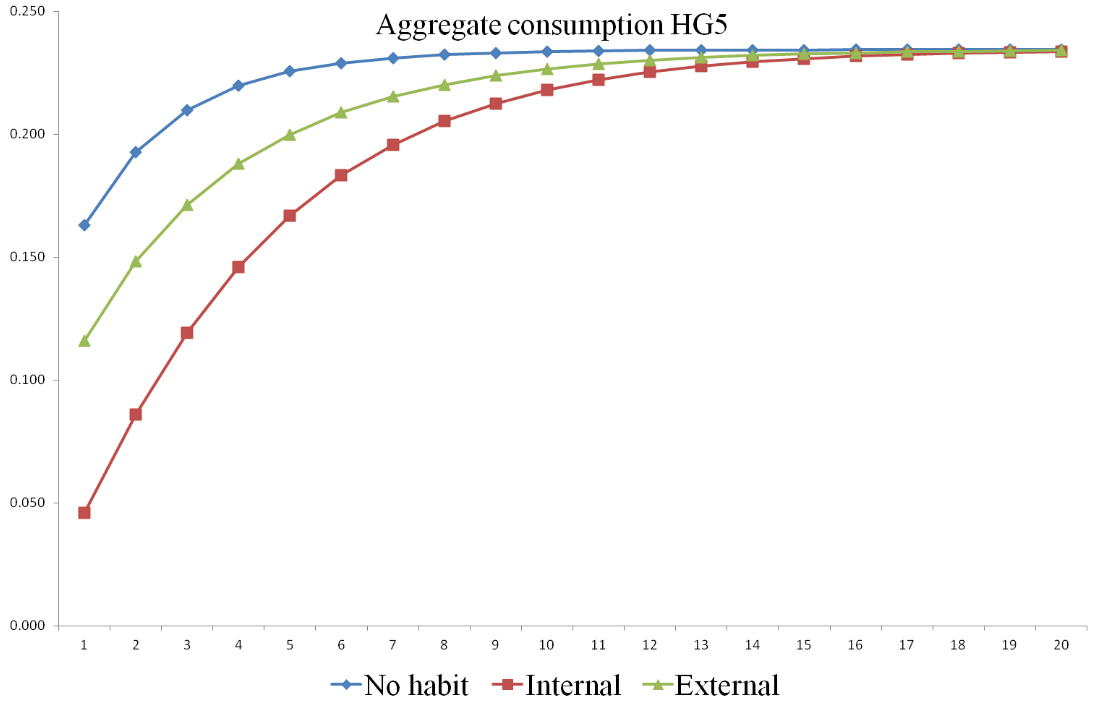


Table 5

Sensitivity analysis

	Short-run impact						**Long-run**	
Elasticity	**Low**			**High**			**Low**	**High**
	No-habit	Internal	External	No-habit	Internal	External		
Economy-wide rebound	48.10	46.47	45.82	81.55	79.99	79.47	49.48	281.60
HH rebound	22.05	18.73	17.91	73.01	69.77	69.15	24.14	268.48
HG1	25.07	19.43	11.99	75.81	70.53	64.03	27.17	209.87
HG2	23.31	19.04	16.80	74.18	70.13	68.13	25.41	210.32
HG3	22.03	18.74	18.53	73.00	69.81	69.67	24.12	211.50
HG4	21.18	18.53	19.21	72.21	69.56	70.28	23.28	213.14
HG5	20.63	18.38	19.78	71.68	69.37	70.82	22.72	214.89

8. Sensitivity analysis: changing the elasticity of substitution

In this section I calculate the magnitude of the household and economy-wide rebound effects for the range of the elasticity of substitution reported in Section 4.

For a 95% confidence interval the elasticity of substitution between energy and non-energy in the household sector fall in the range 0.12 - 0.64 in the short run and 0.14 – 2.61 for the long run.

The simulations carried out here and the corresponding rebound effects reported in Table 5 are the results of running the model with the conventional time separable utility function where the short run and long-run rebounds are obtaining applying the short and long run elasticities respectively.

Our sensitivity analysis predicts a very large range for the rebound effect for the long run. However the range is tighter for the short run. This is due to our long-run estimate confidence interval where the lowest level of the long-run elasticity of substitution is equal to 0.14 while the highest prediction is above the Cobb-Douglas relationship. The long run household rebound fall in between 24.1% and 268.5% while the economy-wide rebound rests between 49.5% and 281.6%.

9. Conclusions

The impact of energy efficiency improvement has commonly been analysed on the production side of the economy, at least in a CGE modelling framework. The main contribution of this paper is to study the impact of energy efficiency improvement in the use of energy in household consumption and show the resulting economy-wide and household rebound figures.

Initially I have estimated the elasticity of substitution between energy and non-energy in household consumption. As expected, demand is more elastic in the short than the long run. Two interesting findings can be observed from the simulation results. First, when I use the long-run elasticity to obtain both the short and long-run impacts, rebounds are lower in the long-run than the short-run. This is the case already identified in previous works using computable general equilibrium models (Allan *et al*., 2006; Hanley *et al*., 2007, Turner, 2009) and in the partial equilibrium context (Allan *et al*., 2010). Second, when the short and the long-run impacts are obtained using the short and the long-run elasticity respectively, rebounds are lower in the short-run than the long run although the presence of disinvestments. This result is instead consistent with previous analytical works (Saunders, 2008; Wei, 2007 and 2010).

Given that households consider the price of energy as given, only when I adjust the *cpi* and the real wage for reductions in the price of energy in efficiency units does the price of energy fall for all the transition path. In the central scenario the increase in efficiency acts as a modification of tastes, changing, as a result, the composition of household consumption. However, when households internalize the efficiency, the *cpi* adjusts in a way to put downward pressure on nominal wage, and thus on prices. The long-run demand for energy decreases more in the central case scenario, where the price of energy rises than the case of adjusted *cpi*, where the price of energy falls. The reason for this is due to the greater output effect yielded when energy price is expressed in efficiency units in the *cpi* equation, driven by a fall in nominal wage and prices which increase the foreign demand for local goods, stimulating further economic activity.

One more issue I analyse here is the extent to which the introduction of habit formations might change the composition of household consumption in order to modify the magnitude of the household rebound. First, we have seen that in the long run the impact is the same, no matter the type of habits persistence introduced in the model. This is because the introduction of habit has only implication for the speed of convergence towards the new equilibrium. However, the short run is different for both the aggregate level of energy consumption and for the five income quintile specified in the model.

It can be seen that, household and economy-wide rebound are lowest for external habit formation and highest when consumers' preferences are defined using a conventional utility function. Furthermore, for the case of external habit persistence, rebound is lowest for the poorest households whilst the percentage of energy savings in richest household is less than in the poorest.

The sensitivity analysis shows that only in the short-run the width of the potential rebound interval is small. However, there is greater uncertainty in the long-run where the calculated rebound values falls within a large range.

Chapter 5

Conclusions

The first two essays presented fall in the area of regional economics. The two target economies are the Autonomous Region of Sardinia and Scotland, respectively. Whilst the third essay deals with environmental problems, specifically the magnitude of the rebound effects from an increase in efficiency, in the use of energy by UK households.

In the first essay, I attempt to contribute to the literature of regional economic models through the incorporation of modern macroeconomic methodology into CGE models. Indeed, regional scientists have attempted to incorporate a macroeconomic methodology into regional empirical analysis by modifying the national macroeconomic framework in order to reflect differences in the regional economic structure. However, the economic modelling frameworks employed for regional policy analysis often lack important regional economic features. Furthermore, advances and new developments in macroeconomic models have not been fully adopted, or are used with delay, by regional economists.

Regional CGE models are a widely used economic modelling framework in regional economics. However, regional CGEs are often static and even those with a dynamic structure are solved recursively, implying adaptive or myopic expectations for economic agents. Thus, in the first essay, I attempt to introduce a forward looking structure into a regional CGE model following the growth model of Abel and Blanchard (1983), rendering the CGE model closer to a real business cycle model. In the model I avoid a slavish application of a typical intertemporal model based on the neoclassical framework. Indeed, it is argued that the conventional neoclassical approach of intertemporal resource allocation seems to be inappropriate from a regional point of view, since the imposition of an intertemporal budget constraint where internal and external debts are made repayable from the private sector does not take place in a regional economy.

We have also seen that, contrary to previous literature, myopic and forward-looking models generate the same results in the long-run. In the past, discrepancy between the two dynamic structures was the result of different closures in defining the investment equation. Given that most of the regional myopic CGE models are static in nature, investments were generally modeled as a fixed share of saving abstracting from any adjustment rule. The only difference between appropriately specified myopic and forward looking CGEs, though of course it may be a significant one, is in the transitional pathway where consumption and investment might diverge.

Unlike the analysis carried out in the second and in the third chapter, the results obtained in the first paper can be generalized to any small open economy. The main aim is only to investigate different consumer closures in a forward looking context and to put in evidence, contrary to previous applications on this topic, different long-run results between myopic and forward looking models are only the consequences of asymmetric specifications incorporated in both models.

The second essay focuses on regional fiscal policy issues. The target country is Scotland which represents one of the most interesting examples in the European Union, given continuing debate over fiscal federalism. The model developed in the first chapter is extended in order to incorporate new findings in the macroeconomic growth literature.

I attempt to investigate the effect of a balanced budget fiscal policy in Scotland and to evaluate the conditions under which there may be a positive impact of fiscal policy on the regional economy. There is a large literature on fiscal policy, especially in the context of national economies. I focus, however, on a part of the literature of fiscal federalism that has not been treated extensively, since this has mostly concentrated on the analysis of intergovernmental transfers

The model suggests that an increase in current government purchases in goods and services has negative multiplier effects only if the elasticity of substitution between private and public consumption is high enough to move downward the marginal utility of private consumers. Expansion in public capital expenditure crowds in consumption and investment even with a high level of congestion. However, crowding out effects might arise in the short-run if agents are myopic.

In the third essay using an intertemporal CGE modelling framework for the United Kingdom I analyse the impact of an increase in energy efficiency in the final consumption of energy. In this chapter I have also estimated the elasticity of substitution between energy and non-energy in household consumption. Regression results suggests, as expected, that the elasticity of substitution between energy and non-energy consumption in goods and services is higher in the long run than the short run.

The extent of the rebound effect changes according to the value of the elasticity of substitution between energy and non-energy goods. I find that the energy saving in consumption is higher the smaller the elasticity of substitution since a lower elasticity reflects less sensitivity to relative price changes and reduces the substitution in favour of energy when its effective price falls. Using the value of the elasticity estimated, I have found that for a costless 5% increase in energy efficiency in the household sector, the rebound effects are in the order of 11% and 67% in the short and long-run respectively. However, the magnitude of the rebound effects change when workers internalize the increase in efficiency in the wage bargaining process. Indeed, the long-run rebound effects is, in this case, around 74% meaning that when energy price is expressed in efficiency units in the *cpi* equation, a greater output effect is generated. This is substantially driven by a fall in nominal wage and prices which increase exports, stimulating further economic activity.

The model developed and used in all three essays suffers from two main limitations. Firstly, the lack of the spatial dimension and secondly, the underlying hypothesis of infinite time horizon optimization in the agents programming problem.

In the context of UK fiscal policy reform a natural extension of the model presented in the second essay would be an explicitly interregional analysis. The interregional model would be beneficial since it would facilitate capturing interregional technological and wages spillovers. This might increase or reduce the impacts identified in this dissertation.

Infinitely lived agents' (ILA) models have been subject to criticism due to their inability to capture intergenerational problems arising especially in a context of fiscal policy reform. For instance, a fiscal policy reform in the UK oriented towards devolution and fiscal federalism might have an initial cost for the first generations, however future generations might be able to reap the benefits. This intergenerational redistribution effects cannot be captured in the contest of ILA model. The natural framework would be an overlapping generation model (OLG) of forward looking households.

APPENDIX A

The mathematical presentation of the model

Prices

$$PM_{i,t} = \varepsilon_t \cdot PWM_i \cdot (1 + MTAX_i) \quad \textbf{(A.1)}$$

$$PE_{i,t} = \varepsilon_t \cdot PWE_i \cdot (1 - TE_i) \quad \textbf{(A.2)}$$

$$PX_{i,t} = \frac{PR_{i,t} \cdot R_{i,t} + PE_{i,t} \cdot E_{i,t}}{R_{i,t} + E_{i,t}} \quad \textbf{(A.3)}$$

$$PQ_{i,t} = \frac{PR_{i,t} \cdot R_{i,t} + PM_{i,t} \cdot M_{i,t}}{R_{i,t} + M_{i,t}} \quad \textbf{(A.4)}$$

$$PIR_{j,t} = \frac{\sum_i VR_{i,j,t} \cdot PR_{j,t} + \sum_i VI_{i,j,t} \cdot \overline{PI}_j}{\sum_i VIR_{i,j,t}} \quad \textbf{(A.5)}$$

$$PY_{j,t} \cdot a_j^Y = \left(PX_{j,t} \cdot \left(1 - btax_j - sub_j - dep_j\right) - \sum_i a_{i,j}^V PQ_{j,t} \right) \quad \textbf{(A.6)}$$

$$UCK_t = Pk_t \cdot (ir + \delta) \quad \textbf{(A.7)}$$

$$PC_t^{1-\sigma^c} = \sum_j \sum_h \delta_{j,h}^f \cdot PQ_{j,t}^{1-\sigma^c} \quad \textbf{(A.8)}$$

$$Pgov_t^{1-\sigma^g} = \sum_j \delta_j^g \cdot PQ_{j,t}^{1-\sigma^g} \quad \textbf{(A.9)}$$

$$w_t^b = \frac{w_t}{(1 + sscee + sscer) \cdot (1 + ire)} \quad \textbf{(A.10)}$$

$$\text{Wage setting} \begin{cases} ln\left[\dfrac{w_t}{cpi_t}\right] = \beta - \varepsilon \ln(u_t) & \text{(Regional Bargaining)} \\ \dfrac{w_t}{cpi_t} = \dfrac{w_{t=0}}{cpi_{t=0}} & \text{(Fixed Real Wage)} \\ w_t = w_{t=0} & \text{(National Bargaining)} \end{cases} \quad \textbf{(A.11)}$$

$$rk_{j,t} = PY_{j,t} \cdot \delta_j^k \cdot A\left(\xi_{j,t}\right)^{\varrho_j} \cdot \left(\frac{Y_{j,t}}{K_{j,t}}\right)^{1-\varrho_j} \quad \textbf{(A.12)}$$

$$Pk_t = \frac{\sum_j PQ_{j,t} \cdot \sum_i KM_{i,j}}{\sum_i \sum_j KM_{i,j}} \quad \textbf{(A.13)}$$

Production technology

$$X_{i,t} = min\left(\frac{Y_{i,t}}{a_i^Y}; \frac{V_{i,j,t}}{a_{i,j}^V}\right) \tag{A.14}$$

$$Y_{i,t} = a_i^Y \cdot X_{i,t} \tag{A.15}$$

$$V_{i,t} = a_{i,j}^V \cdot X_{i,t} \tag{A.16}$$

$$Y_{i,t} = A(\xi_{i,t}) \cdot \left[\delta_i^k \cdot K_{i,t}^{\rho_i} + \delta_i^l \cdot L_{i,t}^{\rho_i}\right]^{\frac{1}{\varrho_i}} \tag{A.17}$$

$$L_{j,t} = \left(A(\xi_{j,t})^{\rho_i} \cdot \delta_j^l \cdot \frac{PY_{j,t}}{w_t}\right)^{\frac{1}{1-\rho_j}} \cdot Y_{j,t} \tag{A.18}$$

Trade

$$VV_{i,j,t} = \gamma_{i,j}^{vv} \cdot \left[\delta_{i,j}^{vm} VM_{i,t}^{\rho_i^A} + \delta_{i,j}^{vir} VIR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.19}$$

$$\frac{VM_{i,j,t}}{VIR_{i,j,t}} = \left[\left(\frac{\delta_{i,j}^{vm}}{\delta_{i,j}^{vir}}\right) \cdot \left(\frac{PIR_{i,t}}{PM_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.20}$$

$$VIR_{i,j,t} = \gamma_{i,j}^{vir} \cdot \left[\delta_{i,j}^{vi} VI_{i,t}^{\rho_i^A} + \delta_{i,j}^{vr} VR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.21}$$

$$\frac{VR_{i,j,t}}{VI_{i,j,t}} = \left[\left(\frac{\delta_{i,j}^{vr}}{\delta_{i,j}^{vi}}\right) \cdot \left(\frac{PI_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.22}$$

$$E_{i,t} = \bar{E}_i \cdot \left(\frac{PE_{i,t}}{PR_{i,t}}\right)^{\sigma_i^x} \tag{A.23}$$

Regional Demand

$$R_{i,t} = \sum_j VR_{i,j,t} + \sum_h QHR_{i,h,t} + QVR_{i,t} + QGR_{i,t} + QHK_{i,t} \tag{A.24}$$

Total Production

$$X_{i,t} = R_{i,t} + E_{i,t} \tag{A.25}$$

Households and other Domestic Institutions

$$U = \sum_{t=0}^{\infty} (1+\rho)^{-t} \frac{C_t^{1-\sigma} - 1}{1-\sigma} \tag{A.26}$$

$$\frac{C_t}{C_{t+1}} = \left[\frac{PC_t \cdot (1+\rho)}{PC_{t+1} \cdot (1+r)}\right]^{-\left(\frac{1}{\sigma}\right)} \quad \textbf{(A.27)}$$

$$W_t = NFW_t + FW_t \quad \textbf{(A.28)}$$

$$NFW_t(1+r_t) = NFW_{t+1} + \sum_h dtr_h \cdot (ssce + ire) \cdot \sum_j L_{j,t} \cdot w_t + \sum_h \sum_{dnginsp} TRSF_{h,dnginsp,t} + \sum_h TRG_h \cdot PC_t + \sum_h REM_h \cdot \varepsilon_t - \sum_{dnginsp} \sum_h TRSF_{dnginsp,h,t} \quad \textbf{(A.29)}$$

$$FW_t(1+r_t) = FW_{t+1} + d^K_{dngins} \cdot rk_{i,t} \cdot \sum_i K_i - \sum_h SAV_h \quad \textbf{(A.30)}$$

$$YNG_{dngins,t} = d^L_{dngins} \cdot w_t \cdot \sum_i L_i + d^K_{dngins} \cdot rk_{i,t} \cdot \sum_i K_i + d^h_{dngins} \cdot rh_{i,t} \sum_i H_i + \sum_{dnginsp} TRSF_{dngins,dnginsp,t} + PC_t \cdot TRG_{dngins} + \varepsilon_t \cdot REM_{dngins} \quad \textbf{(A.31)}$$

$$TRSF_{dngins,dnginsp,t} = PC_t \cdot \overline{TRSF}_{dngins,dnginsp} \quad \textbf{(A.32)}$$

$$SAV_{dngins,t} = mps_{dngins} \cdot YNG_{dngins,t} \quad \textbf{(A.33)}$$

$$QH_{i,h,t} = \delta^{f}_{i,h}{}^{\rho^c_i} \cdot \left(\frac{PC_{i,t}}{PQ_{i,t}}\right)^{\rho^c_i} \cdot C_t \quad \textbf{(A.34)}$$

$$QH_{i,h,t} = \gamma^f_{i,h} \cdot \left[\delta^{hr}_{i,h} \cdot QHR^{\rho^A_i}_{i,h,t} + \delta^{hm}_{i,h} \cdot QHM^{\rho^A_i}_{i,h,t}\right]^{\frac{1}{\rho^A_i}} \quad \textbf{(A.35)}$$

$$\frac{QHR_{i,h,t}}{QHM_{i,h,t}} = \left[\left(\frac{\delta^{hr}_{i,h}}{\delta^{hm}_{i,h}}\right) \cdot \left(\frac{PM_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho^A_i}} \quad \textbf{(A.36)}$$

Government

$$FD_t = (G_t + I_{(g),t}) \cdot Pgov_t + \overline{GSAV} + \sum_{dngins} TRG_{dngins,t} \cdot PC_t - \left(d^k_g \cdot \sum_i rk_{i,t} \cdot K_{i,t} + d^h_g \cdot \sum_i rh_{i,t} \cdot H_{i,t} + \sum_i IMT_{i,t} + \sum_h dtr_h \cdot (ssce + ire_t) \cdot \sum_j L_{j,t} \cdot w_t \; + \overline{FE} \cdot \varepsilon_t\right) \quad \textbf{(A.37)}$$

$$G_t = \sum_i QG_{i,t} \cdot PQ_{i,t} + \overline{GSAV} \tag{A.38}$$

$$QG_{i,t} = \gamma_i^g \cdot \left[\delta_i^{gr} \cdot QGR_{i,t}^{\rho_i^A} + \delta_i^{gm} \cdot QGM_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.39}$$

$$\frac{QGR_{i,t}}{QGM_{i,t}} = \left[\left(\frac{\delta_i^{gr}}{\delta_i^{gm}}\right) \cdot \left(\frac{PM_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.40}$$

Investment Demand

$$QV_{i,t} = \sum_j KM_{i,j} \cdot J_{j,t} \tag{A.41}$$

$$QV_{i,t} = \gamma_i^v \cdot \left[\delta_i^{qvm} \cdot QVM_{i,t}^{\rho_i^A} + \delta_i^{qvir} \cdot QVIR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.42}$$

$$\frac{QVM_{i,t}}{QVIR_{i,t}} = \left[\left(\frac{\delta_i^{qvm}}{\delta_i^{qvir}}\right) \cdot \left(\frac{PIR_{i,t}}{PM_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.43}$$

$$QVIR_{i,t} = \gamma_i^{vir} \cdot \left[\delta_i^{qvi} \cdot QVI_{i,t}^{\rho_i^A} + \delta_i^{qvr} \cdot QVR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.44}$$

$$\frac{QVR_{i,t}}{QVI_{i,t}} = \left[\left(\frac{\delta_i^{qvr}}{\delta_i^{qvi}}\right) \cdot \left(\frac{PI_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.45}$$

Time path of investment

$$J_{i,t} = I_{i,t}\left(1 - bb - tk + \frac{\beta}{2}\,\frac{\left(\frac{I_{i,t}}{K_{i,t}} - \alpha\right)^2}{\frac{I_{i,t}}{K_{i,t}}}\right) \tag{A.46}$$

$$\frac{I_t}{K_t} = \alpha + \frac{1}{\beta} \cdot \left[\frac{\lambda_{i,t}}{Pk_t} - (1 - bb - tk)\right] \tag{A.47}$$

$$\dot{\lambda}_{i,t} = \lambda_{i,t}(r_t + \delta) - R_{i,t}^k \tag{A.48}$$

$$\theta(x_t) = \frac{\beta}{2}\,\frac{(x_t - \alpha)^2}{x_t};\ \text{and}\ x_t = \frac{I_t}{K_t} \tag{A.49}$$

$$R_{i,t}^k = rk_t - Pk_t\left[\frac{I_{i,t}}{K_{i,t}}\right]^2 \theta'_t(I/K) \tag{A.50}$$

Factors accumulation

$$KS_{i,t+1} = (1-\delta)\cdot KS_{i,t} + I_{i,t} \tag{A.51}$$

$$LS_{i,t+1} = \left(1 + \left(\varsigma - \nu^{u}[ln(u_t) - ln\,(\bar{u}^{N})] + \nu^{w}\left[ln\left(\frac{w_t}{cpi_t}\right) - ln\left(\frac{w^{N}}{cpi^{N}}\right)\right]\right)\right)\cdot LS_{i,t} \tag{A.52}$$

$$K_{i,t} = KS_{i,t} \tag{A.53}$$

$$LS_t\cdot(1-u_t) = \sum_j L_{j,t} \tag{A.54}$$

Indirect taxes and subsidies

$$IBT_{i,t} = btax_i\cdot X_{i,t}\cdot PX_{i,t} \tag{A.55}$$

$$IMT_{j,t} = \sum_i MTAX_j\cdot VM_{i,j,t}\cdot PM_{i,t} \tag{A.56}$$

$$SUBSY_{i,t} = SUB_i\cdot X_{i,t}\cdot PX_{i,t} \tag{A.57}$$

Total demand for import and current account

$$M_{i,t} = \sum_j VI_{i,j,t} + \sum_j VM_{i,j,t} + \sum_h QHM_{i,h,t} + QGM_{i,t} + QVI_{i,t} + QVM_{i,t} \tag{A.58}$$

$$TB_t = \sum_i M_{i,t}\cdot PM_{i,t} - \sum_i E_{i,t}\cdot PE_{i,t} + \varepsilon_t\cdot\left(\sum_{dngins}\overline{REM}_{dngins} + \overline{FE}\right) \tag{A.59}$$

Assets

$$VF_{i,t} = \lambda_{i,t}\cdot K_{i,t} \tag{A.60}$$

$$D_{t+1} = (1+r-\tau)\cdot D_t + TB_t \tag{A.61}$$

$$Pgov_{t+1}\cdot GD_{t+1} = \left[1 + r - \tau g + \left(\frac{Pc_{t+1}}{Pc_t} - 1\right)\right]\cdot GD_t\cdot Pgov_t + FD_t \tag{A.62}$$

Steady-state conditions

$$KS_{i,T}\delta = I_{i,T} \tag{A.63}$$

$$R^{k}_{i,T} = \lambda_{i,T}(r_T + \delta) \tag{A.64}$$

$$FD_T = -\left[r - \tau g + \left(\frac{Pc_{t+1}}{Pc_t} - 1\right)\right]\cdot Pgov_T\cdot GD_T \tag{A.65}$$

$$TB_T = -(r-\tau)\cdot D_T \quad \textbf{(A.66)}$$

$$NFW_T \cdot r_T = \sum_h dtr_h \cdot (ssce + ire) \cdot \sum_j L_{j,T} \cdot w_T + \sum_h \sum_{dnginsp} TRSF_{h,dnginsp,T} + \sum_h TRG_h \cdot PC_T + \sum_h REM_h \cdot \varepsilon_T - \sum_{dnginsp} \sum_h TRSF_{dnginsp,h,T} \quad \textbf{(A.67)}$$

$$FW_t \cdot r_T = d^K_{dngins} \cdot rk_{i,t} \cdot \sum_i K_i - \sum_h SAV_{h,T} \quad \textbf{(A.68)}$$

In order to produce short-run results, we have that

$$KS_{i,t=1} = KS_{i,t=0} \quad \textbf{(A.69)}$$

$$LS_{=1} = LS_{t=0} \quad \textbf{(A.70)}$$

$$GD_{t=1} = GD_{t=0} \quad \textbf{(A.71)}$$

$$D_{t=1} = D_{t=0} \quad \textbf{(A.72)}$$

For FL2 equation (A.33) disappear if *dngins=h. We* also add:

$$FW_t = \sum_i VF_{i,t} + Pgov_{t+1} \cdot GD_t + D_t \quad \textbf{(A.73)}$$

$$FW_t(1+r_t) = FW_{t+1} + \Pi_t - \left(\sum_i J_{i,t} + FD_t - TB_t\right) \quad \textbf{(A.74)}$$

In order to run the myopic model from the consumption side, equations (A.26) and (A.27) are substitute with the following:

$$C_t = \sum_{dngins \in \langle H \rangle} YNG_{dngins,t} - \sum_{dngins \in \langle HH \rangle} SAV_{dngins,t} - HTAX_t - \sum_{dngins} \sum_h TRSF_{dngins,h,t} \quad \textbf{(A.75)}$$

To obtain the path of investment equations (A.46 – A.49) disappear and we introduce:

$$I_{i,t} = v \cdot \left[KS^{*}_{i,t} - KS_{i,t}\right] + \delta \quad \cdot KS_{i,t} \qquad \textbf{(A.76)}$$

$$KS^{*}_{i,j} = \left(A\left(\xi_{j,t}\right)^{\rho_i} \cdot \delta_j^k \cdot \frac{PY_{j,t}}{uck_t}\right)^{\frac{1}{1-\rho_j}} \cdot Y_{j,t} \qquad \textbf{(A.77)}$$

Alternatively we can use the following:

$$\frac{I_{i,t}}{KS_{i,t}} = \delta \quad \cdot \left[\frac{rk_{i,t}}{uck_t}\right]^{v} \qquad \textbf{(A.78)}$$

Where v equal 0.5 in (A.75) and 2 in (A.77)

Glossary

i,j	the set of goods or industries
ins	the set of institutions
dins $(\subset ins)$	the set of domestic institutions
dngins $(\subset dins)$	the set of non government institutions
h $(\subset dngins)$	the set of households

Prices

$PX_{i,t}$	output price
$PY_{i,t}$	value added price
$PR_{i,t}$	regional price
$PM_{i,t}$	import price
$PWM_{i,t}$	world price of import
$PE_{i,t}$	price of export
$PWE_{i,t}$	world price of export
$PQ_{i,t}$	commodity price
$PIR_{i,t}$	national commodity price (regional + ROI)
$PI_{i,t}$	ROI price
$rk_{i,t}$	rate of return to capital
w_t	unified nominal wage
w_t^b	after tax wage
Pk_t	capital good price
UCK_t	user cost of capital
$\lambda_{i,t}$	shadow price of capital
PC_t	aggregate consumption price

$PGov_t$	aggregate price of Government consumption goods
ε_t	exchange rate [fixed]

Endogenous Variables

$X_{i,t}$	total output
$R_{i,t}$	Regional supply
$M_{i,t}$	total import
$E_{i,t}$	total export (interregional + international)
$Y_{i,t}$	value added
$L_{i,t}$	labour demand
$K_{i,t}$	physical capital demand
$KS_{i,t}$	capital stock
$LS_{i,t}$	labour supply
$VV_{i,jt}$	Total intermediate inputs
$VR_{i,jt}$	regional intermediate inputs
$VM_{i,jt}$	ROW intermediate inputs
$VIR_{i,jt}$	national intermediate inputs (REG+ROI)
$VI_{i,jt}$	ROI intermediate inputs
$QGR_{i,t}$	regional government expenditure
$QGM_{i,t}$	government expenditure(ROI+ROW)
C_t	aggregated household consumption
$QH_{i,h,t}$	total households consumption in sector *i* for *h*
$QHR_{i,h,t}$	regional consumption in sector *i* for group *h*
$QHM_{i,h,t}$	import consumption in sector *i* for group *h*
$QV_{i,t}$	total investment by sector of origin *i*
$QVR_{i,t}$	regional investment by sector of origin *i*
$QVM_{i,t}$	ROW investment demand
$QVIR_{i,t}$	national investment (REG+ROI)
$QVI_{i,t}$	ROI investment demand
$I_{(g),t}$	Public investment in infrastructure
$I_{j,t}$	investment by sector of destination *j*
$J_{j,t}$	investment by destination *j* with adjustment cost
u_t	regional unemployment rate
$R^k_{i,t}$	marginal net revenue of capital
$SAV_{dngins,t}$	domestic non-government saving

$YNG_{dngins,t}$	domestic non-government income
$TRSF_{dngins,dnginsp,t}$	transfer among *dngins*
$HTAX_t$	total household tax
TB_t	current account balance
U	utility function
$SUBSY_t$	production subsidies

Exogenous variables

$\overline{REM}_t$	remittance for *dngins*
$\overline{FE}_t$	remittance for the Government
$QG_{i,t}$	government expenditure
$GSAV_t$	government saving
$A(\xi_{i,t})$	exogenous technical change
r_t	interest rate
tk	corporation tax
ire_t	rate of income tax

Elasticities

σ	constant elasticity of marginal utility
ϱ_j	between labour and capital in sector *j*
ρ_i^A	in Armington function
σ_i^x	of export with respect to term of trade
μ	of real wage with respect to unemployment rate

Parameters

$a_{i,j}^V$	Input-output coefficients for *i* used in *j*
a_j^Y	share of value added on production
$\delta_{i,h}^f$	share parameter in household demand function
$\delta_j^{k,l}$	shares in value added function in sector *j*
$\delta_{i,j}^{vir,vm,vr,vi}$	shares parameters in CES function for intermediate goods
$\delta_{i,j}^{qvir,qvm,qvr,qvi}$	shares parameters in CES function for investment goods
$\delta_{i,h}^{hr,hm}$	shares parameters in CES function for households consumption
$\delta_i^{gr,gm}$	shares parameters in CES function for government consumption
$\gamma_{i,j}^{vv,vir}$	shift parameter in CES functions for intermediate goods
γ_i^f	shift parameter in CES function for households consumption goods

γ_i^g	shift parameter in CES function for government consumption
$btax_i$	business tax
sub_i	rate of production subsidy
$MTAX_i$	rate of import tax
$KM_{i,j}$	physical capital matrix
mps_{dngins}	rate of saving in institutions *dngins*
$ssce$	rate of social security paid by employees
$sscer$	rate of social security paid by employer
ρ	pure rate of consumer time preference
bb	rate of distortion or incentive to investment
α	a parameter in the adjustment cost function
β	a parameter in the adjustment cost function
δ	rate of depreciation

Appendix B

The bulk of the model has been already outlined in Appendix A. However some of the model characteristics are changed. Given that the utility function is now as in Chapter 3, Eq. (1), the Eq. (A.27) in Appendix A, need to be replaced by Eq. (B.1):

$$\frac{\tilde{C}_t}{\tilde{C}_{t+1}} = \left[\frac{P\tilde{C}_t \cdot (1+\rho)}{P\tilde{C}_{t+1} \cdot (1+r)}\right]^{-\left(\frac{1}{\sigma}\right)} \quad \textbf{(B.1)}$$

And the following equations are added

$$\tilde{C}_t = Z \cdot \left[a^c C_t^{\omega} + (1-a^c) G_t^{*\omega}\right]^{\frac{1}{\omega}} \quad \textbf{(B.2)}$$

$$C_t = \left[Z^{\omega} \cdot a^c \left(\frac{P\tilde{C}_t}{PC_t}\right)\right]^{\frac{1}{1-\omega}} \cdot \tilde{C}_t \quad \textbf{(B.3)}$$

We only need to specify the demand equation for C_t given that in the model government is exogenous (see Eq. (B.5). PC_t is given in Eq. (A.8) while $P\tilde{C}_t$ is endogenously determined.

The representative consumers internalize government consumption so that the Non-Financial Wealth (NFW) is given by the following Eq. (B.4) that substitutes Eq. (A.30):

$$\begin{aligned} NFW_t(1+r_t) = {} & NFW_{t+1} + Pgov_t \cdot G_t \sum_h dtr_h \cdot (ssce + ire) \\ & \cdot \sum_j L_{j,t} \cdot w_t + \sum_h \sum_{dnginsp} TRSF_{h,dnginsp,t} \\ & + \sum_h TRG_h \cdot PC_t + \sum_h REM_h \cdot \varepsilon_t \\ & - \sum_{dnginsp} \sum_h TRSF_{dnginsp,h,t} \end{aligned} \quad \textbf{(B.4)}$$

We introduce a public capital as a new factor of production. This means that the Eq. (A.17) is replaced by the following:

$$Y_{i,t} = A(\xi_{i,t}) \cdot \left[\delta_i^k \cdot K_{i,t}^{\rho_i} + \delta_i^l \cdot L_{i,t}^{\rho_i} + \delta_i^g K_{(g),t}^{d\rho}\right]^{\frac{1}{\varrho_i}} \qquad \textbf{(B.5)}$$

Adding the following:

$$K_{(g)t+1}^{s} = K_{(g)t}^{s} \cdot (1-\delta_{(g)}) + I_{(g)t} \qquad \textbf{(B.6)}$$

$$K_{(g),t}^{d} = K_{(g),t}^{s} \cdot \left[\frac{\sum_i K_{i,t} + LS_t}{\sum_i \overline{K}_i + \overline{LS}}\right]^{\gamma} \qquad \textbf{(B.7)}$$

$$G_i^* = G_i \cdot \left[\frac{LS}{\overline{LS}}\right]^{\gamma} \qquad \textbf{(B.8)}$$

The investment in public infrastructure $I_{(g)t}$ is exogenous.

Glossary

$\tilde{C}_t$	effective consumption
$K_{(g),t}^{d}$	public capital services
$K_{(g),t}^{s}$	public stock of infrastructure
$I_{(g),t}$	investment in public infrastructure
G^*	government expenditure
ω	elasticity of substitution between private and public consumption
γ	congestion parameter
Z	scale parameter
a^c	share parameter
δ_i^g	share parameter
$\delta_{(g)}$	depreciation rate public capital stock
$\overline{LS}$	base year value labour supply
$\overline{KS_\iota}$	base year value supply of capital

In this model the income tax variable, *ire,* become endogenous, contrary to the model run in chapter 2 where income tax rate is fixed to the base year.

Estimates of Government Capital Stocks

At present there is no available information concerning regional public investment, so the first step is to estimate the overall series of Scottish public investment. For the period 1963-2004, Scottish public investment is obtained proportionally to the UK EUROSTAT indicator (2009)[61], defined as total gross fixed public capital formation (GFCF) expressed as a percentage of GDP. Once the aggregate series of Scottish public investment[62] is obtained this is split into four subcategories of capital expenditure available from the Government Expenditure and Revenue Scotland (GERS)[63] 2007-2009: Common services and other public utilities, Health and Education, Infrastructures and Other Utility. Unfortunately GERS (2009) does not supply a sectoral breakdown that follows the NACE.Rev-1 classification. Thus, sectoral public investment is obtained according to the sectoral classification of private investment. In order to apply the inventory approach we also need information relating to the initial public capital stock for the year 1963. To do so, I construct an artificial investment series for the years 1862-1962, which is the result of assuming that investment increased by a given growth rate a year during this period[64]. Now the capital stock can be updated and the rates of depreciation I use differ among subcategories: 15% for infrastructure and 5% for all other sub-categories. The final series is depicted below in Figure B.1.

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[61] http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/dataset?p_product_code=TEC00022

[62] The data for the Scottish GDP series are supplied by the Scottish Government, http://www.scotland.gov.uk /Topics/Statistics/Browse/Economy/GDP/Download.

[63] See table 6.3 at: http://www.scotland.gov.uk/Publications/2009/06/18101733/8.

[64] The rate of growth is obtained using a simple discrete growth formula applied for the period 1862-1963, that allow us to reach the observed level in 1963. The initial value of investment for the year 1862 is equal to 1. A similar approach is used in Kamps 2006 in order to estimate the initial capital stock for 22 OECD countries.

Figure B.1

Public Capital stock. Millions of pounds

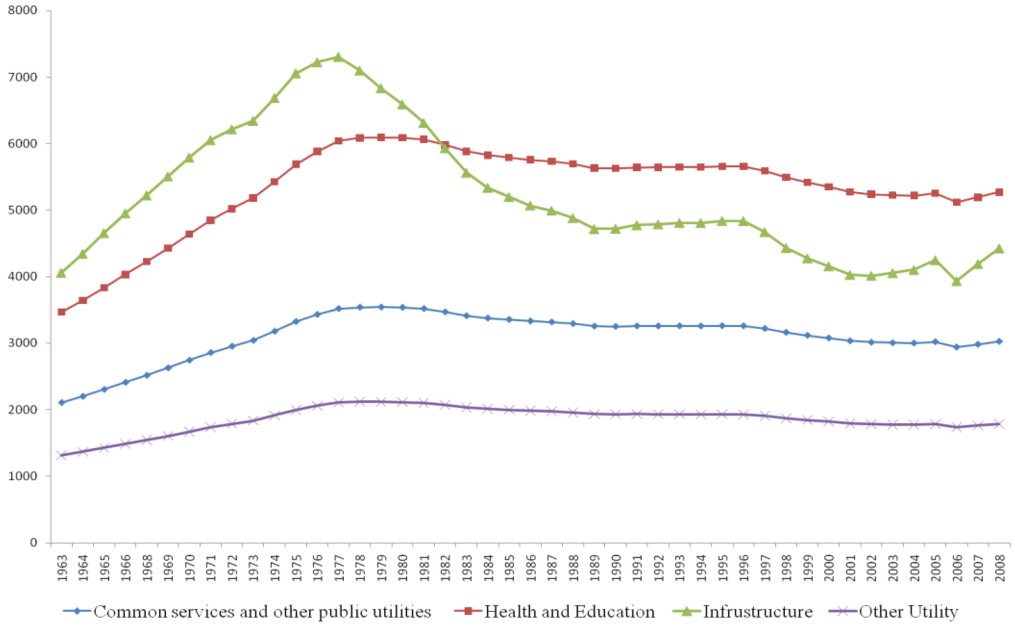
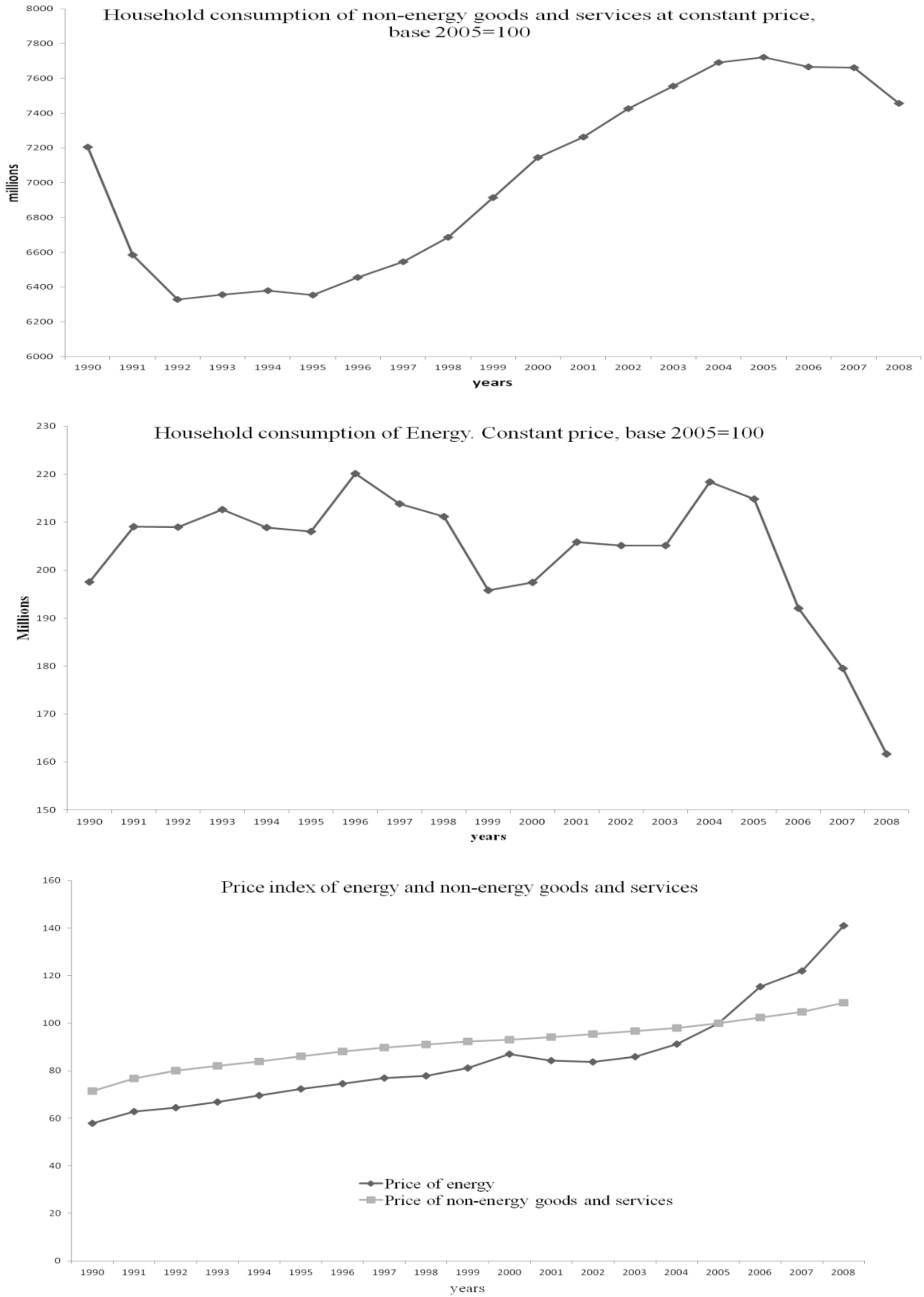


Table B.1. Scottish Social Accounting Matrix for the year 2004. Millions of Pounds

	Agriculture, forestry & fishing	Mining	Manufacturing	Energy and water	Construction	Distribution & catering	Transport & communication	Finance and business	Public admin etc.	Education, health and social work	Other services	Labour	Capital	Public stock	Indirect net taxes	Household_HG1	Household_HG2	Household_HG3	Household_HG4	Household_HG5	FIRMS	Governement	Capital formation	Gov capital formation	STOCK	Turism	Taxes on import	RUK	ROW	Total
Agriculture, forestry & fishing	384	2	648	2	18	170	5	19	6	11	4	0	0	0	0	47	52	111	179	279	0	1	71	7	2	10	0	1052	494	3574
Mining	1	103	889	627	101	10	10	16	3	3	3	0	0	0	0	1	2	3	5	8	0	0	28	3	24	1	0	1103	393	3337
Manufacturing	273	98	1981	137	556	271	259	395	401	223	80	0	0	0	0	138	154	327	526	823	0	0	460	45	60	66	0	13659	10035	30965
Energy and water	42	63	990	2295	15	113	63	127	125	116	38	0	0	0	0	88	98	208	335	524	0	0	0	0	0	0	0	1748	45	7033
Construction	50	451	113	63	2790	91	151	917	462	62	39	0	0	0	0	21	23	49	79	124	0	0	5049	494	129	0	0	1284	90	12532
Distribution & catering	111	60	1031	36	174	375	185	345	94	190	66	0	0	0	0	943	1052	2237	3601	5635	0	2	279	27	27	980	0	850	702	19000
Transport & communication	106	200	626	43	79	1201	2197	1902	416	254	150	0	0	0	0	169	188	400	644	1008	0	0	115	11	2	116	0	2028	478	12335
Finance and business	254	569	1331	215	864	2140	1120	9542	1350	667	845	0	0	0	0	714	796	1692	2724	4263	0	28	1214	119	36	125	0	9974	2298	42880
Public admin etc.	3	9	34	5	19	10	59	528	37	2	6	0	0	0	0	11	12	26	42	66	0	12227	103	10	0	1	0	6	2	13218
Education, health and social work	47	21	110	21	15	71	94	497	416	1837	112	0	0	0	0	238	265	563	907	1419	0	11906	7	1	2	17	0	690	133	19387
Other services	8	22	72	10	8	47	81	263	130	66	951	0	0	0	0	198	220	468	754	1179	0	544	187	18	1	137	0	1863	183	7410
Labour	514	775	7936	655	3269	7513	4051	9618	4579	11800	2526	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	53236
Capital	851	123	3853	1369	2213	3837	1827	12002	1386	1875	1267	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	30604
Public stock	4102	4102	4102	4102	4102	4102	4102	4102	4102	4102	4102			0																45120
Indirect net taxes	-23	55	416	381	54	735	306	1159	778	483	143	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	4488
Household_HG1	0	0	0	0	0	0	0	0	0	0	0	3835	14	0	0	0	0	0	0	0	8	4098	0		0	0	0	18	15	7987
Household_HG2	0	0	0	0	0	0	0	0	0	0	0	5529	28	0	0	0	0	0	0	0	8	3962	0		0	0	0	10	6	9542
Household_HG3	0	0	0	0	0	0	0	0	0	0	0	8717	787	0	0	0	0	0	0	0	179	3947	0		0	0	0	128	114	13872
Household_HG4	0	0	0	0	0	0	0	0	0	0	0	14001	2749	0	0	0	0	0	0	0	537	3446	0		0	0	0	326	294	21354
Household_HG5	0	0	0	0	0	0	0	0	0	0	0	21154	13012	0	0	0	0	0	0	0	2271	2391	0		0	0	0	719	655	40202
FIRMS	0	0	0	0	0	0	0	0	0	0	0	0	8379	0	0	1347	1786	1566	2194	6223	0	855	0		0	0	0	-47	-2555	19747
Governement	-4102	-4102	-4102	-4102	-4102	-4102	-4102	-4102	-4102	-4102	-4102	0	5634	45120	4488	1133	1504	1325	1871	5409	11140	0	10602		0	0	0	301	0	43406
Capital formation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1839	2197	2561	4233	9670	5605	0			0	0	0	734	4155	30996
Gov capital formation	7	3	45	0	494	27	11	119	10	1	18			0														774	426	1936
STOCK	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	485		0	0	0	0	0	485
Turism	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	700	1689	2390
Taxes on import	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0
RUK	662	568	6890	994	1392	1609	1386	3981	1777	1206	786	0	0	0	0	705	762	1486	2061	2216	0	0	7940	774	168	556	0	0	0	37919
ROW	285	213	3999	179	471	782	530	1451	1248	591	376	0	0	0	0	396	430	847	1199	1355	0	0	4455	426	36	381	0	0	0	19650
Total	3574	3337	30965	7033	12532	19000	12335	42880	13218	19387	7410	53236	30604	45120	4488	7987	9542	13872	21354	40202	19747	43406	30996	1935	485	2390	0	37919	19650	

Appendix C

Figure C.1. Time series of the household consumption in non-energy goods and services, energy services and price of non energy (PNE) and price of energy (PE)



The GME estimation

The GME estimation consists to re-parameterize the linear model seen in Eq. (9). Each parameter to be estimated, β_k, (for k=1,2,3) can be parameterized as a discrete random variable with a compact support and M possible outcomes for each parameter to be estimated, $z_{k,j}$ (for j=1....M). We have the following linear system:

$$\beta_k = \sum_{j=1}^{M} z_{k,j} p_{k,j}; \qquad \textbf{(C.1)}$$

where $p_{k,j} \in [0,1]$ are positive weights with the property that

$$\sum_{j=1}^{M} p_{k,j} = 1. \qquad \textbf{(C.2)}$$

Similarly we can write a set of j support points for each error term μ

$$\mu_t = \sum_{j=1}^{M} v_{t,j} w_{t,j}; \qquad \textbf{(C.3)}$$

Where $w_{t,j}$ is the finite support set for the error term and $v_{t,j} \in [0,1]$ represent positive weight that sum up to one:

$$\sum_{j=1}^{M} v_{t,j} = 1; \qquad \textbf{(C.4)}$$

The GME problem can now be stated as:

$$Max\, H(p,w) = -\left[\sum_k \sum_j p_{k,j} \log(p_{k,j}) + \sum_i \sum_j w_{i,j}{}' \log(w_{i,j}) \right]$$

subject to Eq. (9), Eq. (A1)-Eq. (A.4). The error support is ±3σ. Prior information on σ is obtained estimating the model in Eq. (9) by OLS. The support parameter for the constant z_1=[-50, -25, 0, 25, 50] while for z_2=z_3=[-20, -10, 0, 10, 20].

Model description

The full model equations can be found in Appendix A. However some of the model characteristics are now changed, namely: the utility function that now incorporates habit persistence and the consumption structure.

Given the utility function in Equation (1) and the budget constraint as in Equation (2) of Chapter 4, the maximization problem for each household, leads to the equation expressing the evolution of consumption over time:

$$C_{h,t+1} = C_{h,t} - b \cdot C_{h,t-1} \cdot \left[\frac{PC_t\,(1+\rho)}{PC_{t+1}(1+r)} \right]^{-\frac{1}{\sigma}} + b \cdot C_{h,t} \qquad \textbf{(C.5)}$$

Equation (C.5) substitutes Equation (A.27)

The consumption bundle $C_{h,t}$ is defined intra-temporal as a CES combination over non-energy good and services $CNE_{h,t}$, and energy goods $CE_{h,t}$:

$$C_{h,t} = \left[\delta_h^E \cdot \left(AE_{h,t} \cdot CE_{h,t} \right)^{\rho h} + \delta_h^{NE} \cdot \left(ANE_{h,t} \cdot CNE_{h,t} \right)^{\rho h} \right]^{\frac{1}{\rho h}} \qquad \textbf{(C.6)}$$

Where $\rho h = \dfrac{\varepsilon - 1}{\varepsilon}$

Then, from cost minimization we obtain:

$$\frac{CE_{h,t}}{CNE_{h,t}} = \left[\left(\frac{\delta_h^E}{\delta_h^{NE}} \right) \cdot \left(\frac{PE_t^H}{PNE_t^H} \right) \right]^{\frac{1}{1-\rho h}} \qquad \textbf{(C.7)}$$

The composite price for energy and non-energy are as follow:

$$PE_{h,t}^{\;1-\rho h} = \delta_h^E \cdot PQ_{je,t}^{\;1-\rho h} \qquad \textbf{(C.8)}$$

$$PNE_{h,t}^{\;1-\rho h} = \delta_h^{NE} \cdot PQ_{jne,t}^{\;1-\rho h} \qquad \textbf{(C.9)}$$

Then we need to add the demand for Non-Energy goods and services:

$$QH_{jne\subset j,h,t} = \delta_{je\subset j}^{f\ \rho_{jne\subset j}^{c}} \cdot \left(\frac{PC_{jne\subset j,t}}{PQ_{jne\subset j,t}} \right)^{\rho_{jne\subset j}^{c}} \cdot CNE_{h,t} \tag{C.10}$$

Furthermore the demand for Energy goods and services is a CES combination over the composite consumption of Oil and Coal from one hand and Gas and Electricity (CEG) from the other.

$$CE_{h,t}^{oil+coal} = AG_h \left[\delta_h^{Eoil} \left(CE_{h,t}^{oil} \right)^{\rho hz} + \delta_h^{Ecoal} \left(CNE_{h,t}^{coal} \right)^{\rho hz} \right]^{-\frac{1}{\rho hz}} \tag{C.11}$$

$$\frac{CE_{h,t}^{oil}}{CE_{h,t}^{coal}} = \left[\left(\frac{\delta_h^{Eoil}}{\delta_h^{Ecoal}} \right) \cdot \left(\frac{PE_{h,t}^{coal}}{PE_{h,t}^{oil}} \right) \right]^{\frac{1}{1-\rho hz}} \tag{C.12}$$

$$PE_{h,t}^{coal} = PQ_{j=coal,t} \tag{C.13}$$

$$PE_{h,t}^{oil} = PQ_{j=oil,t} \tag{C.14}$$

$$CE_{h,t}^{gas+ele} = AZ_h \left[\delta_h^{Egas} \left(CE_{h,t}^{gas} \right)^{\rho hx} + \delta_h^{ele} \left(CNE_{h,t}^{Eele} \right)^{\rho hx} \right]^{-\frac{1}{\rho hx}} \tag{C.15}$$

$$\frac{CE_{h,t}^{ele}}{CE_{h,t}^{gas}} = \left[\left(\frac{\delta_h^{Eele}}{\delta_h^{Egas}} \right) \cdot \left(\frac{PE_{h,t}^{gas}}{PE_{h,t}^{ele}} \right) \right]^{\frac{1}{1-\rho hx}} \tag{C.16}$$

$$PE_{h,t}^{gas} = PQ_{j=gas,t} \tag{C.17}$$

$$PE_{h,t}^{ele} = PQ_{j=ele,t} \tag{C.18}$$

Glossary

$je\ (\subset j)$	oil, gas,electricity and coal
$jne\ (\subset j)$	non-energy sectors
$C_{h,t}$	household consumption for the 5 income quintile
$CE_{h,t}^{oil+coal}$	household consumption composite (oil+coal)
$CE_{h,t}^{gas+ele}$	household consumption composite (gas+electricity)
$CE_{h,t}^{oil}$	household consumption of oil
$CE_{h,t}^{gas}$	household consumption of gas
$CE_{h,t}^{ele}$	household consumption of electricity
$CE_{h,t}^{coal}$	household consumption of coal
$CNE_{h,t}$	household consumption of non-energy good and services
$CE_{h,t}$	household consumption of energy
$PE_{h,t}^{ele}$	electricity price
$PE_{h,t}^{gas}$	gas price
$PE_{h,t}^{coal}$	coal price
$PE_{h,t}^{oil}$	oil price
$AZ_{h,t}$	scale parameter
b	habit persistence
$AE_{h,t}$	energy efficiency
$ANE_{h,t}$	scale parameter
$AG_{h,t}$	scale parameter
δ_h^{NE}	share parameter
δ_h^{E}	share parameter
δ_h^{Ecoal}	share parameter
δ_h^{Egas}	share parameter
δ_h^{Eele}	share parameter
δ_h^{Eoil}	share parameter
ρh	elasticity of substitution between energy and non energy
ρhx	elasticity of substitution coal and oil
ρhz	elasticity of substitution between electricity and gas

Table C.1 UK Social Accounting Matrix for the year 2004. Millions of pounds

	AFL	SFF	MAE	FDT	TEX	CHE	MNM	MTR	OTM	WAT	CON	DIS	TRA	CFB	ENE	EDU	POS	COAL	OIL	GAS
AFL	1076.39	0.10	3.01	6432.03	3.24	55.06	8.37	23.17	139.06	0.56	240.97	1512.35	35.59	116.15	2.89	86.88	95.14	0.57	1.53	2.90
SFF	0.04	82.99	0.10	273.69	0.02	0.12	0.06	0.16	0.19	0.01	0.97	244.21	14.75	1.17	0.03	0.14	1.27	0.00	0.01	0.03
MAE	2.95	0.06	847.23	23.55	3.21	539.47	127.26	16.97	26.31	0.38	784.89	191.63	64.48	149.75	0.77	8.86	68.32	1.91	8385.88	1445.38
FDT	1829.53	47.39	18.86	9486.00	75.78	166.54	36.14	118.47	126.22	2.64	34.64	14968.65	315.79	1017.29	15.57	397.75	2590.38	0.38	32.39	13.70
TEX	93.28	2.61	0.43	2.05	693.23	134.83	0.86	189.53	215.56	0.04	123.84	519.34	9.65	66.86	5.21	42.98	315.36	0.02	0.60	0.09
CHE	865.19	8.75	369.55	1460.22	262.73	10456.53	666.16	4240.74	1750.84	38.49	9652.42	2741.93	644.62	1675.80	49.98	568.36	4919.49	7.18	30.26	26.06
MNM	41.04	6.64	407.51	762.28	44.65	1071.58	4700.53	11668.92	1508.88	7.35	4274.53	510.38	126.87	241.80	3.04	74.96	176.25	26.13	74.58	23.60
MTR	167.35	33.18	321.91	270.50	49.33	523.37	511.05	11901.43	1134.36	68.08	2002.99	2998.96	1005.07	1846.05	18.19	329.96	9122.03	28.86	27.77	62.21
OTM	317.83	3.29	25.54	1581.75	304.97	1686.41	2149.10	2487.04	12761.41	30.48	3631.95	3041.38	859.65	6307.13	39.41	1888.77	6547.78	8.18	46.70	161.92
WAT	119.77	1.93	15.75	159.88	26.82	184.61	98.05	149.80	84.53	28.13	13.61	81.05	20.26	51.25	5.01	112.72	426.17	1.82	32.72	17.44
CON	219.64	39.97	1011.46	169.35	20.95	180.19	147.23	494.12	113.95	273.86	51460.37	1844.84	1160.71	12673.91	10.07	311.53	4804.82	17.17	180.30	209.11
DIS	2426.20	43.24	414.85	2993.43	1243.08	5157.47	3911.47	10311.54	2658.21	16.51	4158.94	9188.18	3458.99	9023.30	58.22	2292.69	13310.61	100.19	806.70	53.89
TRA	177.54	46.80	1193.22	1914.40	381.50	3224.89	940.04	2269.49	2199.83	16.14	868.17	26810.34	23868.81	11069.59	66.09	1446.22	4713.16	24.36	169.45	38.40
CFB	2010.39	82.09	4087.72	6584.33	1343.28	10539.40	3786.48	12445.03	5546.66	465.45	18953.54	62286.67	20433.21	143659.92	1285.34	6321.68	44632.05	65.13	769.33	949.29
ENE	12.38	0.03	61.50	70.27	22.53	163.84	35.01	191.57	76.42	6.27	91.80	226.27	162.79	689.27	114.20	191.70	1201.34	0.27	12.24	17.19
EDU	4.92	0.00	11.16	70.03	21.49	167.41	32.84	216.38	52.90	7.08	105.99	738.22	457.49	4338.51	290.52	5077.53	4487.06	0.10	9.85	15.68
POS	335.22	35.45	130.34	452.12	110.01	664.05	213.25	712.33	1578.28	71.27	643.66	3204.53	2054.84	10947.70	126.37	988.34	39582.23	5.68	43.15	35.80
COAL	0.00	0.00	0.00	2.32	0.08	14.37	0.06	0.10	1.55	0.00	1.80	0.47	1.00	0.78	0.01	0.01	1.80	4.02	0.00	0.00
OIL	235.28	82.66	15.91	161.48	5.25	94.65	110.32	40.57	32.42	0.83	375.06	1597.73	2439.02	805.30	18.46	176.64	1317.64	8.20	205.71	71.76
GAS	25.00	15.70	166.11	362.44	73.28	797.83	372.52	385.08	380.69	13.83	37.38	354.91	96.02	331.33	10.83	167.46	574.09	5.12	58.04	1171.72
ELE	196.97	36.26	268.13	589.67	109.57	1475.68	978.39	1050.85	752.99	79.27	229.49	1860.56	492.14	1660.56	52.67	448.90	1547.34	34.54	126.32	2001.41
LAB	3342.03	74.87	2651.15	14415.57	3257.56	20144.48	12465.67	33529.46	19669.96	685.59	31561.60	105120.34	35914.75	160168.97	3508.37	57262.48	145008.13	264.46	2283.57	1656.27
CAP	6661.09	308.23	17080.49	5750.80	325.52	4912.17	728.21	5103.76	8199.79	2365.45	32260.26	44794.52	11345.07	196696.25	809.36	4471.57	33342.71	87.69	249.15	1669.37
IBT	1067.14	13.58	122.31	3945.87	584.26	1344.48	684.16	4088.95	2741.17	579.78	8027.22	38044.13	3934.19	27519.56	44.61	3962.49	10846.56	25.83	360.19	971.66
HG1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HG2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HG3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HG4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HG5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FIRMS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GOV	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KFOR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
STOCK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TUR	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIT	242.72	**9.93**	510.64	835.14	342.12	1291.48	749.82	3220.93	1092.81	13.22	794.03	1646.90	663.77	3452.62	116.19	341.28	3779.61	41.11	257.12	764.93
RUK	1290.92	**17.89**	102.64	6654.71	975.23	11069.82	4818.12	19288.73	5510.08	63.14	4815.70	9998.03	6226.75	11945.40	432.08	1448.06	16059.43	44.72	2210.52	0.00
ROW	723.32	**29.60**	1521.55	2488.75	1019.54	3848.67	2234.49	9598.54	3256.64	39.39	2366.26	4907.86	1978.08	10289.01	346.25	1017.04	11263.45	122.51	2251.18	2279.53
Total	23484.12	1023.27	31359.06	67912.63	11299.23	79909.38	40505.65	133743.66	71611.69	4873.25	177512.09	339434.39	117784.37	616745.22	7429.74	89437.00	360734.22	926.16	18625.26	13659.32

	ELE	LAB	CAP	IBT	HG1	HG2	HG3	HG4	HG5	FIRMS	GOV	KFOR	STOCK	TUR	IIT	RUK	ROW	Total
AFL	2.63	0.00	0.00	0.00	819.26	1373.62	2103.89	2947.97	4319.39	0.00	10.17	812.99	3.17	0.00	0.00	882.07	373.00	23484.12
SFF	0.02	0.00	0.00	0.00	2.75	4.61	7.06	9.90	14.50	0.00	0.20	0.08	0.45	0.00	0.00	290.06	73.67	1023.27
MAE	5291.20	0.00	0.00	0.00	14.59	15.64	16.95	16.21	17.62	0.00	0.00	184.68	82.63	0.00	0.00	8296.38	4733.89	31359.06
FDT	29.04	0.00	0.00	0.00	2735.08	4070.08	5884.35	7347.51	9877.41	0.00	0.00	1.06	158.05	0.00	0.00	3970.69	2545.25	67912.63
TEX	0.20	0.00	0.00	0.00	341.96	508.87	735.70	918.64	1234.94	0.00	0.00	570.58	47.91	0.00	0.00	2641.90	1882.16	11299.23
CHE	62.06	0.00	0.00	0.00	599.84	892.62	1290.51	1611.40	2166.24	0.00	0.00	594.86	176.28	0.00	0.00	19284.09	12796.18	79909.38
MNM	291.07	0.00	0.00	0.00	87.21	129.77	187.62	234.27	314.93	0.00	0.00	3294.13	116.49	0.00	0.00	5953.18	4145.47	40505.65
MTR	291.74	0.00	0.00	0.00	2097.79	3121.73	4513.26	5635.50	7575.91	0.00	0.00	9442.13	483.31	0.00	0.00	39037.71	29121.92	133743.66
OTM	174.05	0.00	0.00	0.00	1450.99	2159.23	3121.72	3897.94	5240.08	0.00	0.00	3579.22	71.28	0.00	0.00	4280.18	3756.31	71611.69
WAT	29.64	0.00	0.00	0.00	577.01	618.22	670.25	640.83	696.74	0.00	0.00	0.02	1.52	0.00	0.00	0.00	7.71	4873.25
CON	271.78	0.00	0.00	0.00	995.68	1066.78	1156.58	1105.80	1202.28	0.00	0.01	94718.04	1428.34	0.00	0.00	143.51	79.73	177512.09
DIS	759.94	0.00	0.00	0.00	14133.61	26376.04	42742.96	62731.31	92206.31	0.00	8.24	8170.10	12.69	0.00	0.00	7957.87	12707.60	339434.39
TRA	79.08	0.00	0.00	0.00	1348.23	2516.06	4077.34	5984.07	8795.75	0.00	0.00	402.93	2.63	0.00	0.00	6072.39	7067.44	117784.37
CFB	1629.94	0.00	0.00	0.00	10683.45	19284.99	30978.28	45215.02	70031.98	0.00	132.62	27283.63	229.73	0.00	0.00	25216.07	39812.52	616745.22
ENE	39.62	0.00	0.00	0.00	18.73	33.81	54.31	79.27	122.79	0.00	7.45	84.88	0.00	0.00	0.00	1404.47	2237.49	7429.74
EDU	34.51	0.00	0.00	0.00	1893.06	3417.21	5489.21	8011.89	12409.35	0.00	40332.17	15.72	8.06	0.00	0.00	743.57	977.08	89437.00
POS	126.72	0.00	0.00	0.00	4638.03	8372.22	13448.65	19629.28	30403.10	0.00	209425.22	4253.96	48.35	0.00	0.00	2893.66	5560.43	360734.22
COAL	788.27	0.00	0.00	0.00	11.24	13.86	15.70	17.07	20.44	0.00	0.00	0.01	4.65	0.00	0.00	22.15	4.43	926.16
OIL	194.04	0.00	0.00	0.00	365.44	450.72	510.72	555.26	664.82	0.00	0.00	0.19	0.00	0.00	0.00	5181.49	2907.69	18625.26
GAS	2271.23	0.00	0.00	0.00	853.33	1052.49	1192.59	1296.59	1552.42	0.00	0.00	0.63	0.00	0.00	0.00	0.00	40.69	13659.32
ELE	9581.84	0.00	0.00	0.00	1535.83	1894.27	2146.42	2333.60	2794.05	0.00	0.00	0.48	0.00	0.00	0.00	181.82	17.08	34477.08
LAB	2688.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	655673.32
CAP	6259.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	383421.17
IBT	1986.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	110894.97
HG1	0.00	44259.43	4914.41	0.00	0.00	0.00	0.00	0.00	0.00	16436.46	6818.01	0.00	0.00	0.00	0.00	474.67	316.45	73219.43
HG2	0.00	79839.99	8865.15	0.00	0.00	0.00	0.00	0.00	0.00	29649.89	12299.08	0.00	0.00	0.00	0.00	856.27	570.84	132081.21
HG3	0.00	121016.84	13437.28	0.00	0.00	0.00	0.00	0.00	0.00	44941.59	18642.23	0.00	0.00	0.00	0.00	1297.88	865.25	200201.06
HG4	0.00	167081.79	18552.16	0.00	0.00	0.00	0.00	0.00	0.00	62048.57	25738.37	0.00	0.00	0.00	0.00	1791.92	1194.61	276407.42
HG5	0.00	243475.28	27034.62	0.00	0.00	0.00	0.00	0.00	0.00	90418.54	37506.53	0.00	0.00	0.00	0.00	2611.22	1740.81	402787.00
FIRMS	0.00	0.00	292702.95	0.00	4348.72	7844.70	11890.54	16416.67	23922.73	0.00	85419.87	0.00	0.00	0.00	0.00	8925.65	5950.43	457422.26
GOV	0.00	0.00	17914.60	110894.97	14881.50	26844.88	40689.92	56178.51	81864.56	75954.68	0.00	0.00	0.00	0.00	20218.61	-628.80	-419.20	444394.23
KFOR	0.00	0.00	0.00	0.00	2456.27	8600.37	9969.11	9697.46	10517.67	137972.53	8054.07	0.00	0.00	0.00	0.00	31161.85	-20039.50	198389.83
STOCK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4822.72	0.00	0.00	0.00	0.00	0.00	4822.72
TUR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IIT	52.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20218.61
RUK	1385.97	0.00	0.00	0.00	3582.05	6461.70	9794.27	13522.45	19705.21	0.00	0.00	22432.58	1087.74	0.00	0.00	0.00	0.00	180943.91
ROW	155.66	0.00	0.00	0.00	2747.78	4956.74	7513.14	10373.01	15115.77	0.00	0.00	17724.21	859.43	0.00	0.00	0.00	0.00	121027.42
Total	34477.08	655673.32	383421.17	110894.97	73219.43	132081.21	200201.06	276407.42	402787.00	457422.26	444394.23	198389.83	4822.72	0.00	20218.61	180943.91	121027.42	

Table C.2

	Aggregated IO Sector	**Original Sector Number Included from 123 UK IO**
AFL	Agriculture, forestry and logging	1+2
SFF	See fishing and See firming	3
MAE	Mining and extraction	5+6+7
FDT	Mfr food, drink and tobacco	Aug-20
TEX	Mfr textiles and clothing	21-30
CHE	Mfr chemicals etc	36-53
MNM	Mfr metal and non-metal goods	54-61
MTR	Mfr transport and other machinery, electrical and inst eng	62-80
OTM	Other manufacturing	31-34+81-84
WAT	Water	87
CON	Construction	88
DIS	Distribution	89-92
TRA	Transport	93-97
CFB	Communications, finance and business	98-107+109-114
ENE	R&D	108
EDU	Education	116
POS	Public and other services	115+117-123
COAL	Coal (Extraction)	4
OIL	Oil (Refining and distribution of Oil and Nuclear)	35
GAS	Gas	86
ELE	Electricity	85

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