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Working paper

The economic impacts of UK trade-enhancing industrial policies and their spillover effects on the energy system

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Abstract

The wider impacts of energy policy on the macro-economy are increasingly recognised in the academic and policy-oriented literatures. Additionally, the interdependence of energy and economy implies that a (policy) change in the non-energy system impacts on the energy system. However, such spillovers on the energy system have not been extensively researched. We begin by analysing the impacts of export promotion policies - a key element of the UK's Industrial Strategy - on the energy system and energy policy goals. As the impacts of such policies are, in large part, transmitted via their effects on the economy, we adopt a computable general equilibrium model - UK-ENVI - that fully captures such interdependence. Our results suggest that an across-the-board stimulus to exports increases total energy use significantly. This does not come directly through energy exports, but indirectly through the energy sectors' linkages to other sectors. Export led growth therefore impacts on energy use - and significantly so. This in turn is likely to have an adverse impact on emission targets. Policy makers should be aware of the fact that a successful implementation of the Industrial Strategy may create significant tensions with the UK's Clean Growth Strategy, for example, and with the goals of energy policy more generally. The importance of this effect will in practice depend upon: the mix of goods and services that are exported (an issue that we shall address once the export strategy is published); the success of low-carbon policies. Ultimately, a knowledge of the nature and scale of these spillover effects of economic policies on the energy system creates the potential for more effective and efficient policy making.

Key words: energy policy, industrial strategy, trade policy

JEL: C68, D58, Q43, Q48

1. Introduction

The wider impacts of energy policy on the macro-economy are increasingly recognised in the academic and policy-oriented literatures. For example, recent contributions to the academic literature on energy efficiency policies emphasise the stimulus to economic activity that these typically generate. For example, for analyses of energy efficiency in production and consumption respectively see Allan et al. (2007), Hanley et al. (2009) and Lecca et al. (2014), and for their impacts on distributional issues see Figus et al. (2017). Within policy communities there is a developing recognition that the wider impacts of energy efficiency policies should be taken into account as proposed in the "multiple benefits" approach of the International Energy Agency (2015), rather than focussing exclusively on energy (and emissions) savings.

Indeed, some governments emphasise energy efficiency improvements explicitly as economic development policies (e.g. the Scottish Government, 2017), as well as a potential source of energy savings (e.g. Figus et al, 2018a; Turner et al, 2018). Of course, these developments reflect the fundamental interdependence of energy (and emissions) and the economy: policy actions in any one system generate spillover effects in the other. Neglect of this interdependence may prove problematic for policy.

The interdependence of the energy systems and the economy naturally also implies that any changes in the economy impact on the energy system. The experience of the great recession, for example, provides dramatic evidence of such dependence, with total UK energy consumption falling by over 6% between 2008 and 2009 when the UK economy contracted by around 4% (BEIS, 2017a). However, these spillovers are not necessarily negative, and "double dividends" (or even "multiple benefits") are possible, where policies simultaneously stimulate economic activity and reduce emissions (and potentially also contribute to other policy goals). While this interdependence is, of course, widely recognised, it has not featured prominently in assessing the likely impact of economic policies, such as industrial and fiscal policies: rather they have tended to focus on the primary economic objectives of these policies, including Gross Domestic Product (GDP) and employment. In principle, (non-energy) economic policies are likely to have significant influences on the energy system, the neglect of which may lead to inefficiencies in the design of appropriate energy and economic policy. The importance of this in practice depends on the strength of the interdependencies between both systems and, in particular, the scale of the impact of economic (non-energy policies) on energy policy goals.

It has been suggested that the impacts of economic policies on the energy system have not been extensively researched. This perceived lack of systematic analysis is highlighted in a recent literature review by Cox et al. (2016). This review found only a small number of research papers (49 of the 576 papers considered) that dedicated their analysis to this question, and only 25 of these focus specifically on the UK. These papers were divided further into categories with the smallest number of dedicated analyses found in communications, culture and sport, education, health, industry and international trade. The greatest number of dedicated analyses within the UK-focused literature was on 'planning policy' and 'work policy'.

Cox et al. (2016) however, note that these research papers tend to focus on a single aspect of the energy system, such as disposable income spent on fuel and passenger miles travelled, and there seems to be a lack of system-wide approaches that link the elements together. The literature review concluded that future research should cover both the relationship between non-energy policies and non-energy phenomena. Moreover, the relationship between non-energy phenomena and energy impacts should be system-based, comparative, and multi-scalar (Cox et al., 2016). However, in the context of the energy-economy-environment modelling literature there has in fact been widespread recognition of the impact of the economy and economic policies on energy use, even if the primary emphasis has tended to be on the effects of energy and environmental policies. An example is the literature on the Environmental Kuznets Curve, which posits that rising prosperity will ultimately be accompanied by falling pollution, following an earlier period in which growth is accompanied by increasing pollution (see, e.g. Grossman and Kreuger, 1994; Jaffe et al., 2003; Vollebergh et al., 2009 and Cui et al., 2017).

The multi-sectoral computable general equilibrium (CGE) approach which we employ here captures the interdependence of the economy and energy systems and allows us to automatically track the impact of key energy and economic policy interventions on the main goals of both sets of policies and so can be used ultimately to develop a more holistic perspective on the conduct of policy.[1] In particular, the intention is ultimately to create a framework that explicitly recognises, and seeks to quantify, the scale of spillovers from economic and energy policies to energy and economic policy goals respectively. Where these spillovers prove to be significant, accounting for them through better coordination of economic and energy policies would create the potential to deliver improved outcomes for both.

In this paper we analyse the potential impacts of successful UK industrial, business and innovation policy on the UK economic and energy systems, as well as the corresponding energy policy goals. Two key pillars of the UK Industrial Strategy are concerned with ‘encouraging trade’ and ‘boosting productivity’ (BEIS, 2017b). In the current paper, we analyse the system-wide effects of successful export strategies on the economy and energy use.

Our primary focus here is on the comparatively unexplored impacts of economic policies on the energy system and their effects on energy policy goals such as energy use (and emissions), energy intensity and energy security. However, the impacts of such policies are, in large part, transmitted via their impact on the economic system, so that we have to adopt an approach that fully captures such interdependence. While there has been some discussion of the economic aspects of the UK’s new industrial policy (see e.g. IPPR, 2017, PWC, 2017, and KPMG, 2017) there has been little analysis of the likely implications for the energy system.

This paper is organised as follows. Section 2 provides a brief overview of the UK’s industrial strategy, with a particular focus on “encouraging trade”. Section 3 outlines an ex-ante labour market analysis of an export demand stimulus. Sections 4 and 5 outline the structure of our energy-economy-environment model of the UK economy, paying particular attention to the linkages between the economy and energy components of the model and the simulation strategy. We present results in Section 6 and 7, and brief conclusions in Section 8.

[1] The use of CGE models to analyse economy-environment interactions is widespread (see Bergman, 2005 for a review).

2. UK Industrial strategy

The UK Government has set out an explicit Industrial Strategy aimed at 'creating an economy that boosts productivity and earning power throughout the UK' (BEIS, 2017b). The strategy is defined as 'coordinating a wide range of economic policies to achieve particular objectives, which need not be purely economic' (House of Commons, 2018).

The industrial strategy identifies five foundations which the government argues are 'essential attributes of every successful economy'. These are: ideas (R&D, innovation), people (skills and education), infrastructure (broadband, energy, transport), business environment (support for specific sectors and SMEs), and places (tackling regional disparities) (BEIS, 2017b).

Improving these five areas is expected to enable the UK to tackle a series of 'Grand Challenges'. These include: clean growth (low carbon technologies across the economy), mobility (low carbon transport, automation, and infrastructure), AI and data revolution (how to embed and maximise the advantages of AI and data), and aging society (healthcare and labour market challenges) (BEIS, 2017b).

Also, as part of the ambition to be a more 'Global Britain', 'encouraging trade' is considered a critical pillar of the Government's strategy. Although 'trading more, not less' seems to be key, precise policies or quantifiable measures are not explicitly stated. Although, a more detailed UK Export Strategy is currently being drafted.

Despite being concerned with coordinating policy, the strategy does not consider explicitly trade-offs (or complementarities) across policies, and how such tensions and conflicting demands could be overcome. As we illustrate in analytical and empirical analysis, increasing trade has a significant impact on the energy system, and energy policy goals in particular. This analysis therefore has two objectives; first, to explore how economic (i.e. non-energy) policies impact the energy system, and, second, to demonstrate the potential usefulness of the CGE modelling approach in capturing and quantifying the interdependencies between the economy and energy systems.

3. Ex-ante labour market analysis of an export demand stimulus

In this section we provide some analytical insight into the factors underlying the impact of the export demand stimulus that would result from a successful 'Global Britain' UK trade promotion policy. We focus on the labour market to highlight the implications of alternative perspectives. For simplicity, we assume that the increase in demand is insufficient to generate a reaction from the Bank of England's Monetary Policy Committee, so that no financial 'crowding out' occurs.[2]

Figure 1 represents the short- and long-run interactions of the general equilibrium labour demand and supply curves in the UK labour market. The analysis is comparative static in that

[2] In effect we treat the UK 'as if' is operating in a 'liquidity trap'.

it can be used to illustrate the impact on the equilibrium real wage and employment, of exogenous export disturbances to the UK economy.

In Figure 1, the demand for labour is a general equilibrium relationship, which incorporates the entire system-wide consequences of a change in the real wage. The curve does not necessarily have a negative slope in employment-real wage space, because as the real wage falls so too does labour income and demand. However, for the default parameter values of our CGE model (described in Section 4) the beneficial competitiveness effects of a reduction in the real wage, which stimulates exports, dominates the adverse income effects. This is what we would expect for a comparatively 'small' (as a proportion of total world trade), open economy like the UK.

The initial equilibrium is represented in Figure 1 by the intersection of the labour demand and supply curves, at point *A*, generating the initial equilibrium employment and real wage levels rw_0, and E_0. The stimulus to exports shifts the general equilibrium demand curve for labour to the right, indicating that more labour is demanded at each real wage. The labour demand curve shifts from D_o to D_{SR}. In the short run, where sectoral capital stocks are fixed, the rightward shift is limited. However, this tends to push up capital rates, spurring sectors to invest in capital, and leads to increased capacity and a greater demand for labour in the long run, shifting the demand curve from D_{SR} to D_{LR}.

Of course, the alternative visions of the effective supply of labour, or labour market closures, as we outline in more detail in Section 4.3, are crucial to determining the impact of this stimulus to demand on wages and employment. These alternatives are reflected in Figure 1.

Our default model specification embodies a wage curve which reflects an inverse relation between the rate of unemployment and the real wage. There is substantial international evidence in support for such a model specification. Blanchflower and Oswald (2005), for example, provide a review on recent research literature on wage curves found across different countries. Empirical evidence for the existence of a wage curve in the UK is given, amongst others, by Barth et al. (2002), Bell et al. (2002), Black & FitzRoy (2000), and Collier (2000). In the employment-real wage space of Figure 1, the wage curve, or bargained real wage function (BRW), is illustrated with an upward sloping curve, reflecting the positive relation between the level of employment and workers' bargaining power.

Under our default assumption and benchmark BRW case, workers are able to bargain higher wages as the labour market tightens. At the initial equilibrium an excess demand for labour is created and the increased bargaining power of workers exerts upward pressure on the real wage. This leads to a degree of crowding out through the induced loss in competitiveness. The new long-run equilibrium is established at point *B*, where both and employment and the real wage increase to E_1 and rw_1 respectively. Since economic activity is stimulated, so too is the demand for energy used in both production (intermediates) and final demand.

While, as we have noted, there is compelling international evidence in favour of our default wage curve specification, we consider a number of alternative labour market closures, so as to reflect alternative visions of how the UK labour market operates. We do this for two main reasons. First, there exists genuine uncertainty about the way that the aggregate UK labour market currently operates and there has been considerable controversy surrounding the issue (e.g. Bell & Blanchflower, 2018). Secondly, we wish to check the extent to which spillovers from economic policies to the energy system vary with alternative visions of UK labour market behaviour. This allows us, as far as is practical within the UK-ENVI model, to check that our conclusions are robust with respect to the choice of any particular model of the UK labour market.

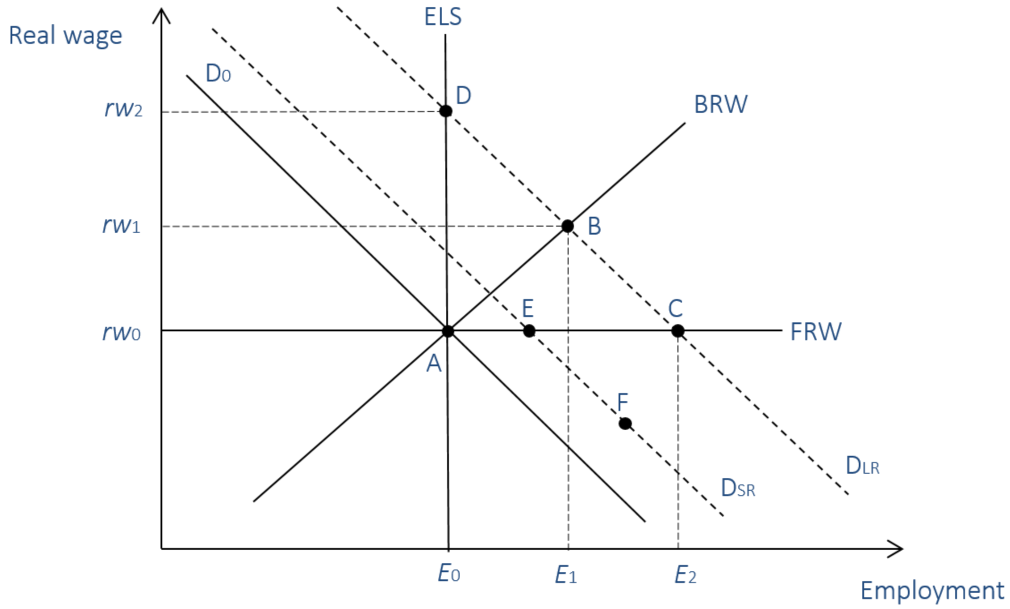
One alternative vision of the labour market is that it is characterised by excess capacity over a range, so that any changes in labour demand can be met by a corresponding change in the level of employment, but at a fixed real wage (FRW). Such a case could also be motivated in terms of the presence of 'real wage resistance': workers seek to maintain the real value of their take home pay, regardless of the nature of any macroeconomic demand disturbance. In this case, the effective labour supply curve is horizontal through point A, and employment adjusts in response to labour demand through changes in the unemployment and participation rates. Essentially, only quantities change since prices are invariant across long-run equilibria, with the new equilibrium at point *C* in Figure 1, and there is no crowding out of economic activity[3]. The real wage is, of course, unchanged, but employment increases significantly to E_2. This corresponds to the simple Keynesian multiplier case, and the multi-sectoral results emulate the behaviour of an Input-Output system with entirely passive supply side in the long run. Since the stimulus to economic activity is greater in this case than for BRW, we expect the use of energy to be greater too, both in production and in final demands.

A further alternative perspective on the labour market, often assumed by national CGE models, assumes continuous full-employment (see e.g. Partridge and Rickman (2010) for a brief discussion). Here we assume an exogenous labour supply (ELS) curve (and participation rate). Employment is effectively fixed, as is reflected in the vertical ELS curve through point A in Figure 1. Following the demand stimulus, a new long-run equilibrium is established where the real wage rises to rw_2: the real wage rises until it dampens the stimulus to demand entirely at point *D*. Of course, there is complete crowding out in terms of employment, which remains fixed at E_0. In a multi-sectoral context GDP may change as resources are reallocated across sectors in response to the demand stimulus and significant upward pressure on real wages, but the direction will depend on sectoral export, labour and intermediate intensities and key elasticities. However, if GDP increases, it is likely to be a much more modest change than is associated with either the BRW or FRW variant. Accordingly, we would expect any stimulus to energy use in production and final demands to be less than in the other cases.

Under present assumptions the fixed nominal wage (FNW) case generates the same results as the FRW case in the long run, since prices (and real and nominal wages) do not change. In the short run, the stimulus to employment and real wages is less than in the long run. In the FRW case, for example, short-run equilibrium is established where FRW intersects the short-run general equilibrium labour demand, at point *E*. In fact, the FNW vision implies an even greater short-run stimulus to the real economy since at point *E* prices have risen, so with a fixed nominal wage the real wage must have fallen. The FNW equilibrium lies on the short-run demand curve, but at a real wage that lies below that at *E*, so equilibrium employment will be higher (as, for example, at point *F*).

[3] Input-Output is a general equilibrium system with fixed coefficient technologies, an absence of capacity constraints and an infinitely elastic supply of labour. McGregor et al. (1996) demonstrate that regional CGEs generate IO results in long-run equilibria given these assumptions.

Figure 1: The system-wide labour market impact of a stimulus to export demands.



Since, in general, the expansion in the real economy is less in the short-run than in the long-run, so too will be the stimulus to total energy use. In general, we would expect total energy use – in both production and final demand – to increase with the level of economic activity, and so the energy impacts will be ranked similarly to the likely employment (and GDP) impacts.

4. Model and data

We simulate the economic and energy system impacts of a successful export-promotion strategy that generates a significant "across-the-board" stimulus to UK exports using a computable general equilibrium (CGE) model of the UK, UK-ENVI. In practice it seems likely that the export strategy that will form a part of the UK's industrial strategy will involve sectoral targeting of export promotion and this could have a significant influence on the impact on both the economic and energy sub-systems. However, since at the time of writing this strategy had not been published we focus here on an across-the-board stimulus. The UK-ENVI model was purpose built to capture the interdependence of the energy and non-energy sub-systems. Versions of this model have been employed, for example, to analyse the impacts of increased efficiency in the industrial use of energy (Allan et al., 2007), identify the impacts of energy efficiency programmes on households (Figus et al., 2017), and to identify total energy rebound effects of improvements in household energy efficiency (Lecca et al., 2014).

We adopt the forward-looking variant of the UK-ENVI model, according to which households' consumption and firms' investment are governed by intertemporal optimisation. In the following sections we provide a description of the main characteristics of the model, with a particular emphasis on the linkages between the economic and energy sub-sectors.[4]

4.1. Consumption and trade

We model the consumption decision of five representative households *h* as follows:

$$C_{h,t} = YNG_{h,t} - SAV_{h,t} - HTAX_{h,t} - CTAX_{h,t} \tag{1}$$

where total consumption *C* is a function of income *YNG*, savings *SAV*, income taxes *HTAX*, and taxes on consumption *CTAX*.

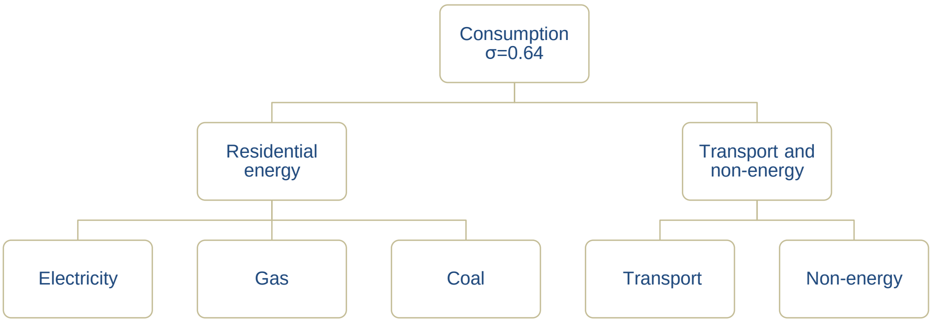
Consumption is modelled to reflect the behaviour of a representative household that maximises its discounted intertemporal utility, subject to a lifetime wealth constraint. The solution of the household optimisation problem gives the optimal time path for consumption of the bundle of goods C_t. To capture information about household energy consumption, consumption is allocated within each period and between energy goods and non-energy and transport goods and services (including fuel use in personal transportation) as indicated in the top level of the consumption structure shown in Figure 2. This choice is made in accordance with the following constant elasticity of substitution (CES) function:

$$C_{h,t} = \left[\delta_h^E \left(EC_{h,t}\right)^{\frac{\varepsilon_h - 1}{\varepsilon_h}} + (1 - \delta_h^E) TNEC_{h,t}{}^{\frac{\varepsilon_h - 1}{\varepsilon_h}}\right]^{-\frac{\varepsilon_h}{\varepsilon_h - 1}} \tag{2}$$

where ε is the elasticity of substitution in consumption, and measures the extent to which consumers substitute residential energy consumption, *EC*, for non-energy and transport consumption, *TNEC,* δ ϵ (0,1) is the share parameter. For simplicity (and in the absence of better information), in all households we impose a value, 0.61, for ε that is the long-run elasticity of substitution between energy and non-energy estimated by Lecca et al. (2014). The consumption of residential energy includes electricity, gas and coal, as shown in Figure 2, although the share of coal consumed by households represents less than 0.01% of total energy consumption. Within the energy bundle, given that we do not focus on inter-fuel substitution in the analysis below, we impose a small but positive elasticity.

[4] We provide the full mathematical description of the model in Appendix A.

Figure 2: The structure of consumption



Moreover, we assume that the individual can consume goods produced both domestically and imported, where imports are combined with domestic goods under the Armington assumption of imperfect substitution (Armington, 1969):

$$QH_{i,t} = \gamma_i^f \cdot \left[\delta_i^{hir} \cdot QHIR_{i,t}^{\rho_i^A} + \delta_i^{hm} \cdot QHM_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{3}$$

where *QH* is total household consumption by sectors, *QHIR* is consumption of locally produced goods, and *QHM* is consumption of imported goods. With the price of imports being exogenous, substitution between imported and domestically produced goods depends on variations of national prices.

It must be noted that the Armington assumption has implications for the decisions of both producers and consumers. The choice over imported or domestic inputs for firms depends on their relative prices, as well as the Armington elasticity. Similarly, consumers choose over imported and domestic goods depending on relative prices and the Armington elasticity. Intermediate purchases in each industry are modelled as the demand for a composite commodity with fixed (Leontief) coefficients. These are substitutable for imported commodities via an Armington link, which is sensitive to relative prices. Given the importance of the Armington elasticities to trade we identify the implications of different values of these elasticities in our sensitivity analysis.

4.2. Production and investment

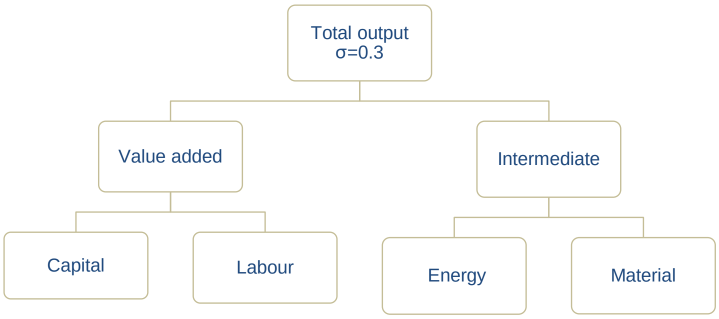
The production structure of each of the thirty production sectors is characterised by a capital, labour, energy and materials (KLEM) nested CES function. As we show in Figure 3, the combination of labour and capital forms value added, while energy and materials form intermediate inputs. In turn, the combination of intermediates and value added forms total output in each sector.

Following Hayashi (1982), we derive the optimal time path of investment by maximising the value of firms, V_t, subject to a capital accumulation function $\dot{K}_t$, so that:

$$Max\ V_t \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t [\pi_t - I_t(1+g(x_t))]\ subject\ to\ \dot{K}_t = I_t - \delta K_t \tag{4}$$

where π_t, is the firm's profit, I_t, is private investment, $g(x_t)$ is the adjustment cost function with $x_t = I_t/K_t$ and δ is depreciation rate. The solution of the optimisation problem gives us the law of motion of the shadow price of capital, λ_t, and the adjusted Tobin's q time path of investment (Hayashi, 1982).

Figure 3: The structure of production



4.3. The labour market

As already touched upon in previous sections, we consider a number of alternative labour market closures. Our default model specification embodies a wage curve which reflects an inverse relation between the rate of unemployment and the real wage. Wages are thereby determined within the UK in an imperfectly competitive context, according to the following bargained real wage (BRW) specification:

$$\ln\left[\frac{wb_t}{cpi_t}\right] = \varphi - \epsilon \ln(u_t) \qquad \text{where } wb_t = \frac{w_t}{1+\overline{\tau}_t} \tag{5}$$

In equation 5, w_t/cpi_t is the real take home wage, φ is a parameter calibrated to the steady state, ϵ is the elasticity of wage related to the level of unemployment u_t, and $\overline{\tau}_t$ is the income tax rate. So here the real consumption (after tax) wage is negatively related to the rate of unemployment (Blanchflower & Oswald, 2005), which is an indicator of workers' bargaining power.

The working population is assumed to be fixed and exogenous. This model implies the presence of involuntary unemployment (with BRW lying above the competitive supply curve for labour).

Conventional CGEs of national economies often make the simplifying assumption of an entirely exogenous labour supply (with both population and the participation rate invariant): that is labour supply exhibits a zero elasticity with respect to the real wage. This exogenous labour supply (ELS) vision of the market implies that employment is fixed.

$$L^s = \overline{L^s} \tag{6}$$

Of course, this vision of the labour market implies that the UK operates under a very tight supply constraint. Note that, in the short run, both capital and labour are fixed in each sector in this case, and so too is value-added. Aggregate GDP can only vary in response to disturbances that alter the allocation of activity across sectors. Furthermore, employment is effectively fixed even in the longer-term, and is, of course, invariant to any change in demand, although capital stocks can adjust in response to changes in rental rates.[5]

Some take the view that workers in the UK bargain to maintain their real wage - 'real wage resistance' - that results in a fixed real wage (FRW) model (at least in the absence of productivity growth). This model implies:

$$\frac{w_t}{cpi_t} = \frac{w_{t=0}}{cpi_{t=0}} \tag{7}$$

This case effectively implies an infinitely elastic supply of labour over the relevant range. In stark contrast to the ELS case, here the real wage is fixed, and any demand disturbances will be reflected only in employment changes (over a range).

The ELS and FRW cases represent limiting cases of the responsiveness of the effective supply of labour to the real consumption wage, with elasticities of zero and infinity respectively. The BRW case represents an intermediate case in which the effective (bargaining-determined) level of employment varies positively with the real consumption wage.

While these cases provide a useful range of alternative visions of the UK labour market, recent experience casts some doubt on the current relevance of the BRW or FRW hypotheses, since real wages have been falling despite a fall in the unemployment rate. There is clearly some evidence of a degree of nominal wage inflexibility. Here we illustrate the likely implications of this by exploring the limiting case of a fixed nominal wage (FNW):

$$w_t = w_{t=0} \tag{8}$$

[5] In the longer-term population and labour supply can, of course, increase through natural population growth. For simplicity we abstraction from that here. Migration flows could also alter labour supply, but we assume that net migration is zero here. However, the fixed real wage model, discussed below, emulates many of the features of a system with endogenous (flow) migration.

4.4. Government

The Government in UK-ENVI collects taxes and spends the revenue on a range of economic activities. For most of the analysis of the present paper we do not close the government budget constraint. Given that we are dealing with an export-led expansion in economic activity we expect there to be an increase in tax revenues and an associated contraction in the public sector deficit. Maintenance of a given deficit would imply either an expansion in government spending or a reduction in tax rates. However, in a forthcoming analysis we shall systematically investigate the energy-system impacts of fiscal policy changes. Here we isolate the energy impact of the export stimulus, in part to avoid conflating these effects with the consequences of an induced fiscal expansion.

However, we do briefly illustrate the consequences of this assumption, and impose a public sector budget constraint as an element of our sensitivity analysis. We constrain the Government to maintain a constant budget balance. If the aggregate fiscal deficit is taken to be fixed, any changes are constrained to be balanced-budget in nature. The given fiscal deficit is maintained by either adjusting taxation or expenditure as:

$$\overline{GOVBAL_T} = GY_t - GEXP_T$$

where (9)

$$GY_t = d_g KY_t + IBT_t + \bar{\tau}_t \cdot LY_t + \overline{FE}_t$$

where *GOVBAL* is the government budget which is equal to the difference between government income *GY,* and government spending *GEXP.* GY is given by the share d_g of capital income *KY* that is transferred to the Government, Indirect business taxes, *IBT,* revenues from labour income *LY* at the rate τ[6], and foreign remittance FE.

In the base year GOVBAL is negative, indicating a fiscal deficit that we assume to be passive in most of our present analysis. However, in our sensitivity analysis we illustrate the consequences of a binding public sector budget. In that analysis we assume that the Government absorbs the budgetary impacts of any change in the economy by adjusting expenditure and keeping household income tax rates fixed.[7]

[6] Note that the income tax rate τ is fixed by default.

[7] We do not explore the consequences of varying tax rates here since this generates complex supply-side responses. We shall explore this in a subsequent analysis.

4.5. Dataset: income disaggregation and energy use

To calibrate the model we follow a common procedure for dynamic CGE models which is to assume that the economy is initially in steady state equilibrium (Adams & Higgs, 1990). We calibrate the model using information from the UK Social Accounting Matrix (SAM) for 2010.[8]

The UK-ENVI model has 30 separate production sectors, including 6 main energy supply industries that encompass the supply of coal, refined oil, gas and electricity[9]. We also identify the transactions of UK households (by income quintile), the UK Government, imports, exports and transfers to and from the rest of the World (ROW).

The SAM constitutes the core dataset of the UK-ENVI model. However other parameter values are required to inform the model. These often specify technical or behavioural relationships, such as production and consumption function substitution and share parameters. Such parameters are either exogenously imposed, based on econometric estimation where available, or determined through the calibration process.

5. Simulation strategy

The main focus of this paper is empirically to identify the currently unexplored impacts of economic policies on the energy system. Specifically, the present paper investigates the impact of successfully 'encouraging trade' in line with the UK's Industrial Strategy (BEIS, 2017b), which we assume to be reflected in a significant stimulus to exports. We proceed by exploring the system-wide economic effects of this stimulus to exports, focussing particularly on impacts on the energy system.

We shall, in due course, explore the transmission mechanisms of trade-enhancing policy instruments that are targeted on individual sectors, and assess their efficacy explicitly. However, the Industrial Strategy currently does not provide detail on such targeting or on how it plans to measure the 'success' of these policies in terms of scale of impacts, time-frames, or the precise policy instruments used.

Accordingly, for now we proxy the impact of a successful trade-enhancing policies by an exogenous (and costless) 5% increase in international export demands across all sectors.

The economy is taken to be in long-run equilibrium prior to the increase in exports, so that when the model is run forward in the absence of any disturbance it simply replicates the base year dataset (the 2010 SAM) in each period. The results presented here are typically percentage changes in the endogenous variables relative to this unchanging equilibrium (unless otherwise specified). All of the effects reported are therefore directly attributable to the exogenous shocks to exports. Given that the CGE model uses annual data, we take each period in the adjustment process to be one year.

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[8] The SAM is produced by the Fraser of Allander Institute and available for download at: http://www.strath.ac.uk/business/economics/fraserofallanderinstitute/research/economicmodelling/

[9] See Appendix B for the full list of sectors in the aggregate 30 sector 2010 UK SAM.

To observe the adjustment of all the economic variables through time, simulations are run for 50 periods (years). Results for a range of economic and energy use are reported. While we report selected period-by-period results, the focus is primarily on two conceptual time periods. The first is the short run (SR), which is the period immediately after the introduction of the exogenous shock. Capital stocks are fixed in the SR at industry level. In the long run (LR) capital stocks fully adjust, across all sectors, to the shock, and are again equal to their desired levels. However, we also report period-by-period values for a sample of key variables.

6. Simulation results

We start by discussing the aggregate long-run results for the FNW-FRW closures since this is a useful benchmark, whose properties are well-known (as discussed in our general equilibrium analysis in Section 3). We then discuss the main differences between the FNW-FRW, BRW (our default model), and ELS closures. This is followed by a detailed discussion of the potential impacts on the energy-systems, sectoral results, and a discussion of short-run results.

The short- and long-run macroeconomic simulation results for a 5% increase in international exports, reported in percentage changes from base year, across the different labour market closures, are summarised in Table 1.

The adjustments seen in the long-run for the FRW-FNW closures are akin to the results found in IO modelling. With no supply restrictions applying, prices remain unchanged in the long run (McGregor et al., 1996). The long-run results for the FRW and the FNW closures are the same as they both tie down wages in the long-run with no changes in prices.

As there are no changes in prices (CPI remains unchanged from base), there is no crowding out of exports in the long run so that exports increase by the full 5%. The increase in exports stimulates aggregate demand, which increases consumption, investment, and GDP, by 1.46%, 2.35% and 2.08% respectively. Capital stocks rise in the long run by 2.35%, with net investment driven by the gap between the capital rental rate and the user cost of capital that opens in the short run.

The stimulus to investment and enhanced capacity reinforces the expansion (and the impact on employment). This expansion stimulates the demand for labour so that employment rises by 1.91%, and the unemployment rate falls by 1.8 percentage points. Labour income and capital income both rise, by 1.91% and 2.35%, respectively. Export industries tend to be more capital intensive than the aggregate economy, so that the demand for capital increases slightly more than that for labour (this is shown in Appendix B in the final column).

The public sector deficit falls by 7.3% in the long run, a fall from £98bn to £91bn, as tax revenues rise in response to the stimulus to economic activity. We investigate the consequences of closing the Government budget constraint in the sensitivity analysis of Section 7.

Imports increase by 2.12% along with increases in domestic demand (we discuss this in more detail when considering sectoral results). In the base period net exports are negative i.e. the UK economy imports more than it exports. The stimulus to exports thereby decreases the negative trade balance by 0.19%.

When considering the BRW case, as we would expect from our discussion in Section 3, the stimulus to the real economy is significantly less (as compared to FRW/FNW) because real wages and prices rise in response to the excess demand for labour. So GDP in the BRW case increases by 0.95%, which is less than half of the 2.08% stimulus under FRW/FNW. The rise in the real and nominal wage pushes up the CPI (by 0.75%), reducing competitiveness and crowding out some of the stimulus to exports, which now rise by only 3.63% in the long run. The rise in consumption of 1.16% is less than under FRW (1.46%), but the decline is mitigated by the fact labour income actually rises more in this case, with the higher real wage more than offsetting the lower employment impact (0.75% as against 1.91%).

Next we consider the ELS case of continuous full-employment, where we assume an exogenous labour supply curve (and participation rate). As we know, following the demand stimulus the real wage rises so as to choke off any excess demand for labour at the original level of employment. So employment is unchanged, but the real wage and the CPI rise by 1.43% and 1.24%, significantly more than under the BRW (0.86% and 0.75%). This results in much greater crowding out of exports, which now only rise by 2.75%, and a much bigger stimulus to imports (of 3.19%). The sectoral distribution of effects does result in a modest stimulus to GDP of 0.23%, but this is significantly less than under the BRW and FRW-FNW closures.

Again, as we would expect from our theoretical analysis that the short-run impacts are muted given that the capital stock is fixed in the short run both in total and in its distribution across sectors, and prices increase in all cases so that there is some induced loss in competitiveness, and exports are always crowded out to a degree. As anticipated, the GDP (and employment) effects in the short run are ranked as: FNW>FRW>BRW>ELS (and indeed the impact is zero in this case).

These are the kind of economic impacts that are typically associated with export led growth strategies. In general, under our default BRW model, a stimulus to exports will benefit the host economy in terms of an increase in GDP, employment, consumption and investment. Indeed across all models of the labour market we find that key economic indicators are beneficially impacted by successful export promotion strategies. Furthermore, the public sector deficit is typically reduced, so that government expenditure could be expanded. With both consumption and the provision of public services enhanced, it would be reasonable to suggest aggregate welfare is enhanced.

These results therefore appear reassuring for the conduct of UK industrial strategy in that key economic indicators move in the desired direction as a consequence of a successful export promotion strategy. However, there are substantial and currently unexplored impacts on the energy-system, which we now discuss. We focus on the BRW case, our preferred model.

Total energy use (intermediate plus final demand) increases significantly, by 1.71%. Electricity use increases by 1.26% and Gas use by 1.35%. This reflects increases in energy use in both production and final demand, notably consumption. Energy use in production (total intermediate) increases by 1.41% in the long run in the BRW case. This is driven by the increase in intermediate demands from exporting sectors (we explore this in more detail when considering sectoral results), and their linkages to the energy sectors.

Table 1: Short and Long-run effects of a 5% increase in international exports. In % changes from base year.

	Long-run			Short-run			
	FRW-FNW	BRW	ELS	FNW	FRW	BRW	ELS
GDP	2.08	0.95	0.23	0.64	0.30	0.19	-
CPI	-	0.75	1.24	0.92	1.09	1.24	1.40
Unemployment rate (pp difference)	-1.80	-0.71	-	-0.98	-0.46	-0.29	-
Total employment	1.91	0.75	-	1.04	0.49	0.31	-
Nominal gross wage	-	1.61	2.68	-	1.09	1.58	2.28
Real gross wage	-	0.86	1.43	-0.91	-	0.34	0.87
Households wealth	1.36	1.06	0.87	0.43	0.50	0.55	0.61
Households consumption	1.46	1.16	0.96	0.70	0.56	0.75	0.83
Labour income	1.91	2.38	2.69	1.04	1.58	1.90	2.28
Capital income	2.35	1.99	1.76	3.84	2.97	2.83	2.43
Government budget	-7.03	-2.42	0.59	-1.00	0.22	0.76	1.55
Investment	2.35	1.28	0.59	3.35	2.46	2.01	1.36
Total energy use (intermediate+final)	2.53	1.72	1.21	1.30	1.04	1.03	0.93
- Electricity	2.03	1.26	0.77	1.16	0.83	0.81	0.68
- Gas	1.98	1.35	0.94	0.81	0.63	0.70	0.68
Energy use in production (total intermediate)	2.36	1.41	0.80	0.79	0.55	0.52	0.42
Energy consumption (total final demand)	2.91	2.44	2.15	1.56	1.49	1.59	1.64
- Households	1.43	1.30	1.21	0.75	0.68	0.92	1.05
- Investment	2.27	1.26	0.60	2.24	1.55	1.40	1.05
- Exports	5.00	4.11	3.53	2.66	2.63	2.55	2.49
Energy output prices	-	0.50	0.82	0.92	0.98	1.06	1.13
Energy output	2.62	1.65	1.02	0.65	0.48	0.47	0.40
Non energy output	2.14	1.13	0.48	0.90	0.58	0.48	0.31
Energy intensity (Total energy use/GDP)	0.44	0.76	0.98	0.66	0.74	0.84	-
Total imports	2.12	2.77	3.19	3.07	3.06	3.28	3.41
Total exports	5.00	3.63	2.75	3.00	2.73	2.49	2.25
Net exports (exports-imports)	-0.19	-0.04	0.06	0.04	0.05	0.09	0.12
- Electricity	2.18	2.27	2.33	2.42	2.25	2.41	2.45
- Gas	2.29	2.46	2.58	2.68	2.53	2.70	2.77

Note: Short- and long-run are two conceptual time periods. The short run (SR) is the period immediately after the introduction of the exogenous shock. Capital stocks are fixed in the SR at industry level. In the long run (LR) capital stocks fully adjust, across all sectors, to the shock, and are again equal to their desired levels. The short-run applies to a period of a year; the adjustment period to the long-run varies but is typically complete within 7-12 years.

The use of energy in consumption (total final demand) sees a significant increase of 2.44%. This increase is mainly driven by the stimulus to exports. Although household and investment demands for energy increase by 1.30% and 1.26%, this constitutes a marginal contribution to total final demands in absolute terms. Energy consumption is thereby driven here mainly through exports.

Energy use increases across the board in response to the export stimulus. Furthermore, energy use increases significantly relative to GDP, employment and investment. Energy intensity, defined here as energy use per unit of GDP, increases. In fact, this is true across all labour market models: energy intensity increases significantly as a consequence of a successful export promotion strategy. It appears that exports are thereby rather energy intensive, a characteristic we discuss in more detail when considering sectoral results. This is a potentially important spillover from a successful UK industrial strategy to the energy system.

In the base period net exports of Electricity and Gas are negative, dominated strongly by imports. The stimulus to exports however does not decrease this negative trade balance. This is because exports are small relative to imports so that the corresponding stimulus to imports outweighs the increase in exports.

Energy output prices increase by 0.5% reflecting the stimulus to energy demand created by the expansion, as well the increase in labour and material costs. This in turn impacts household consumption, for example.

Figures 4 and 5 summarise selected long-run results at the individual sector level for the 5% increase in international exports, for the BRW closure, and Appendix C gives a more detailed set of sectoral results. Recall that all sectors receive the same percentage export demand stimulus, but sectoral impacts vary because of their different sectoral characteristics, including export and energy intensities. Appendix B gives a summary of key sectoral characteristics and a full description of abbreviated sector names, which we refer to henceforth.

The energy sectors are: sector 2, Mining & quarrying (MIN); sector 3, Crude Petroleum & Natural Gas & Metal Ores & coal (CRU); sector 4, Other Mining & mining services (OMI); sector 16, Electricity, transmission & distribution (ELE), and sector 17 Gas; distribution of gaseous fuels through mains; steam & air conditioning supply (GAS).

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Consider first the impacts on sector 28, Education health and defence (EDU). This sector mainly serves the domestic market (as detailed in Appendix B) so that it does not benefit directly from the export stimulus. Moreover, this sector is also labour intensive so it is particularly impacted by the increase in wages with sectoral employment actually falling in the long run by 0.02%. This sector therefore experiences a comparatively small stimulus to output of 0.10%. This sector, however, accounts for a large proportion of total imports so that the 0.22% increase in imports in that sector accounts for 17% of total imports.

The Construction sector (CON), sector 20, receives around 52% of total incomes from spending on investment goods. This is by far the largest capital share of output across all sectors. This sector therefore experiences a strong stimulus through its domestic demand linkages. The MIN sector experiences a sharp increase in imports. This increase in imports, however, accounts for below one percent of total imports in absolute terms.

Energy intensive sectors (besides the energy supply sectors themselves), such as sector 10, Chemicals & Pharmaceuticals (CHE), sector 27, Services (SER), and sector 21, Wholesale & Retail Trade (WHO), also exhibit strong export linkages. These sectors consume a significant proportion of total energy, and also contribute a significant proportion to total exports. These sectors therefore contribute to the energy intensity of exports (in addition to the exports of the energy supply sectors). The WHO and SER sectors also contribute large shares to total imports with 7% and 13% respectively.

The direct impact of the export stimulus on the ELE & GAS sectors is relatively muted given that they mainly serve the domestic market. They contribute below 1% of total exports and around 5% of total imports. However, they do have strong domestic demand linkages to other sectors (as noted above) and so respond to their expansion. The corresponding impact on employment, however, is relatively small given that these sectors are not labour intensive.

It is important to note that energy use in production increases more than output, and much more than employment in each sector. This could be due in part to a relative price effect, where real wages are rising significantly but energy prices less so.

From these results it is evident that aggregate energy impacts are driven by key characteristics of individual sectors. Although all sectors receive the same percentage export demand shock, sectoral impacts vary significantly because of their heterogeneous nature. Sectors differ in terms of, for example, energy intensity, export intensity and domestic demand linkages and these seem to be driving aggregate impacts on energy. This highlights potential policy trade-offs, particularly at the individual sector level. Increasing exports may generate inadvertent, negative impacts on energy policy goals, if the impacted sectors are also energy intensive.

Given that real wages (and capital incomes) are rising, Households experience rising incomes and wealth and so their total consumption - of energy and non-energy goods & services – increases, as we have already noted. Figure 6 summarises the long-run impacts on households' consumption, income, the share of income spent on Electricity & Gas, and non-energy goods & services, across household quintiles, where HH1 is the lowest income quintile. The share of income spent on energy- and non-energy goods and services increases across all Household quintile groups.

Although we do not attempt to investigate the impacts on precise measures of fuel poverty (or poverty in general) we can identify the impact on the share of disposable income spent on energy (defined as the energy sectors share in each household quintiles consumption). For this we focus on the lowest household income quintile, where fuel poverty/poverty is highest (BEIS, 2017c). The proportion of the lowest household income group's spending on energy increases so on that basis our measure of 'fuel poverty' deteriorates, although on the other hand that group's total income and total expenditure on all goods also increase. It could be considered as an undesirable outcome for fuel poverty when considering that the lowest household income quintile is now paying higher prices for its Electricity & Gas. However, it could be argued that this may not be problematic given that household incomes and consumption are increasing.

The other goals of energy policy are similarly adversely affected: affordability (as indicated by the price of energy) declines, although real incomes are actually increasing by more than energy prices so that there is a sense in which 'real' affordability is improved.

The time path adjustments for GDP, employment, and total energy use are detailed in Figure 7. This figure shows how these variables increase throughout all of the simulation periods. Moreover, these results highlight that total energy use increases more than proportionately to GDP, so that there is a significant negative spillover effect from successful export promotion policies to the energy system. There is a potential conflict between economic policies that aim to increase exports, and energy policy goals that aim to reduce emissions. Furthermore, as noted earlier, these spillover effects, which appear to be substantial across all treatments of the labour market, are typically absent from current debates about the effectiveness of economic policies.

It is important to note that the potential impact of export promotion on emissions identified here need not in fact materialise. First, if export promotion is focussed on goods and services associated with comparatively low emissions, the rise in energy use and emissions would be mitigated. Second, if the clean growth strategy results in further decarbonisation of the energy sector, increased exports could occur without a corresponding increase in emissions. However, our simulations here isolate the effects that are solely attributable to an across-the-board export stimulus and the results suggest that it is very likely that this would be associated with higher carbon emissions than would otherwise be the case. In order to avoid an actual increase in emissions some other policy would require to be implemented (e.g. "low carbon" export promotion; improvements in energy efficiency; further decarbonisation of the energy system). Aspects of the UK Government's industrial and green growth strategies are presumably intended to combine in this complementary manner, but a knowledge of the existence and scale of spillovers of such policy combinations is likely to facilitate an appropriately coordinated response.

Figure 4: Long-run effects on output, employment, and energy use by individual sectors of a 5% increase in international exports, BRW closure. In % changes from base year.

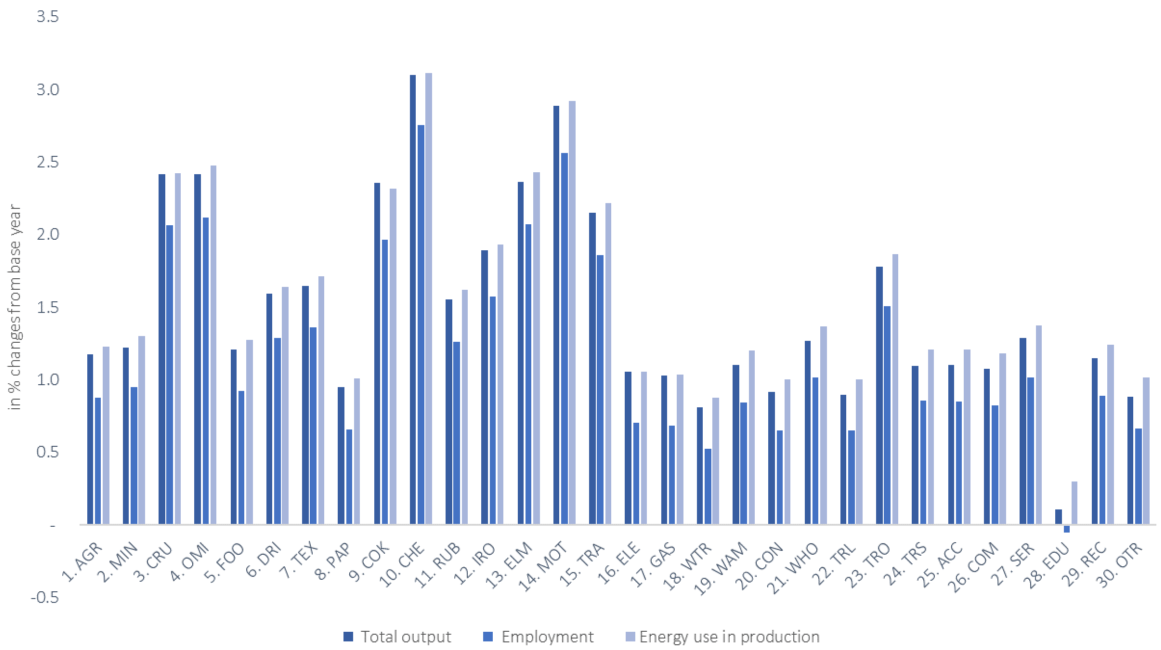


Figure 5: Long-run effects on output price, imports and exports at individual sectors of a 5% increase in international exports, BRW closure. In % changes from base year.

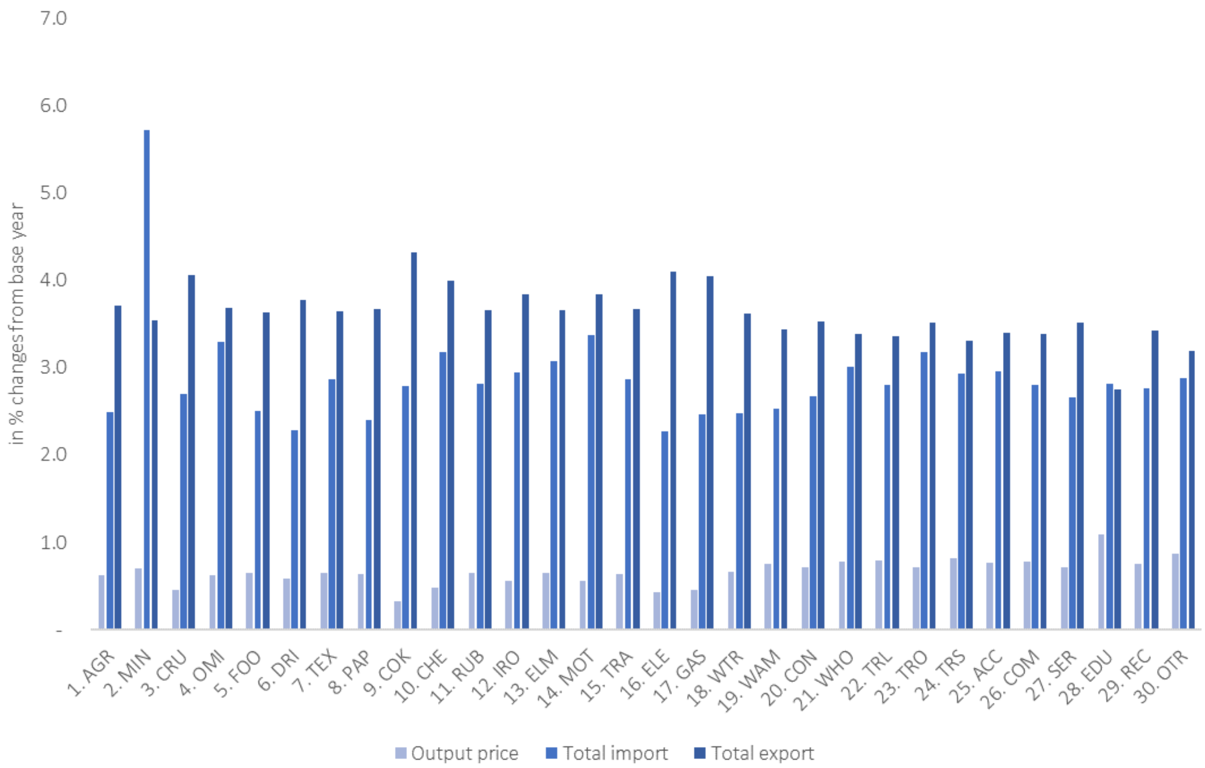


Figure 6: Long-run effects on Household quintiles of a 5% increase in international exports, BRW closure. In % changes from base year.

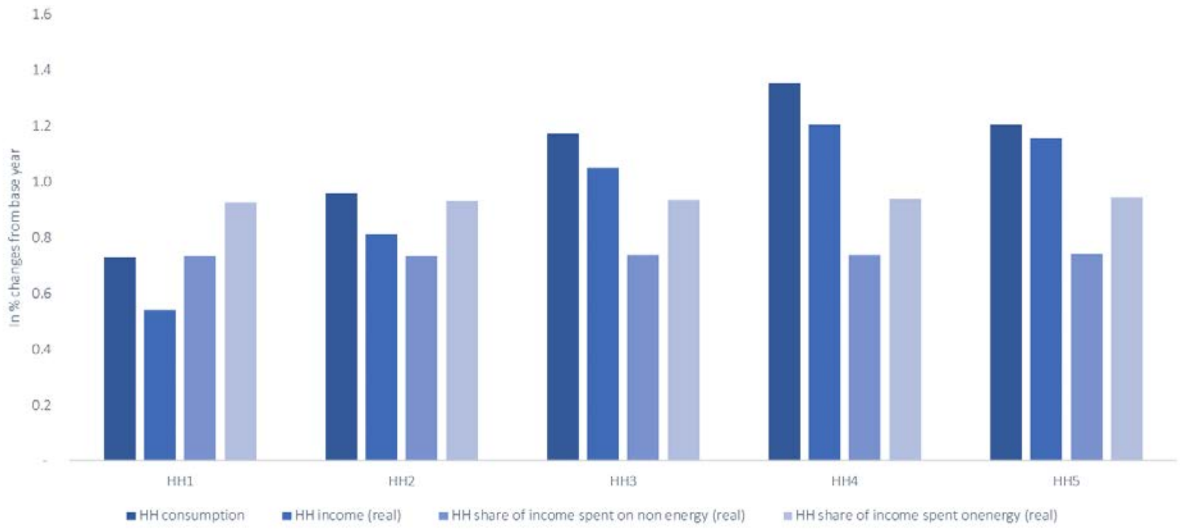
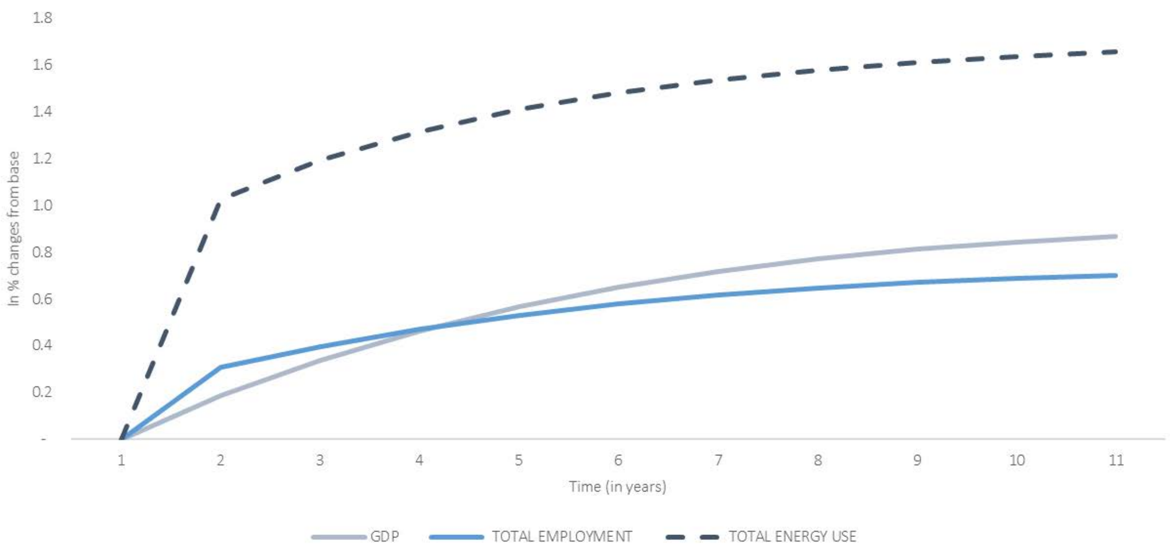


Figure 7: Aggregate transition path for GDP, employment, and total energy use of a 5% increase in international exports. In % changes from base year.



7. Sensitivity analysis

Our central results presented in the previous section depend upon the structural data embedded in the base-year values of the UK SAM. However, they are also sensitive to the choice of key parameter values in the UK-ENVI model, and the recycling of additional government revenues generated by the export stimulus, for example. The values of the Armington trade elasticities are particularly important in the case of an export driven demand shock as they alter the sensitivity of trade to price changes.

Here we explore the sensitivity of results to: the degree of the openness of the UK economy (by varying Armington trade elasticities for imports and exports); and the imposition of a public sector budget constraint.

Table 2 summarises the results for the sensitivity analysis for the Armington trade elasticities for imports and exports for the BRW closure. Appendix D details the full set of results. This elasticity is varied from 1.5, 2.0, and 2.5, where 2.0 is the central elasticity value used in the model. We only report the results for the BRW closure here as the basic mechanism outlined below also holds for the alternative labour market closures.

Table 2: Sensitivity analysis for Armington trade elasticities. Short and Long-run effects of a 5% increase in international exports, BRW closure. In % changes from base year.

	Long-run			Short-run		
	σ = 1.5	σ = 2	σ = 2.5	σ = 1.5	σ = 2	σ = 2.5
GDP	1.01	0.95	0.90	0.21	0.19	0.17
CPI	0.80	0.75	0.70	1.35	1.24	1.15
Total employment	0.80	0.75	0.71	0.34	0.31	0.29
Real gross wage	0.92	0.86	0.81	0.37	0.34	0.31
Total energy use (intermediate+final)	1.79	1.72	1.66	1.06	1.03	1.00
Energy intensity (Total energy use/GDP)	0.77	0.76	0.75	0.85	0.84	0.82
Total imports	2.66	2.77	2.86	3.06	3.28	3.45
Total exports	3.54	3.63	3.71	2.29	2.49	2.66

Essentially, as the degree of substitutability is increased from 1.5 to 2.5 the system becomes more sensitive to competitiveness changes. To recall, the demands for UK goods are sensitive to regional prices relative to the (assumed) constant prices for the ROW. Imports also exhibit this relative-price sensitivity.

The higher the trade elasticity the greater the sensitivity of trade to relative price changes so that adverse competitiveness effects are enhanced. With less domestic demand for domestic goods there is a smaller stimulus to consumption, output, and the demand for labour. As the

Armington elasticity is increased there are more imports and the domestic market experiences a smaller stimulus. In the labour market there is less upward pressure on wages.

The impacts of such changes to the openness of the UK economy on the energy-system (and energy policy goals) seem to be stark. Focusing on the long run it can be seen that whilst the impact on GDP decreases as the Armington elasticity is increased, total energy use increases (mainly through increases in final demands): energy intensity falls. Overall, changes to the Armingon trade elasticities illustrate that the degree of substitutability between domestic produced goods and imported goods has a significant impact on aggregate results.

Table 3 details a summary of the results for the sensitivity analysis conducted around the public sector constraint for the BRW closure. Appendix E details the full set of results – across all four labour market closures. Here we illustrate the consequences of a binding public sector budget where we assume that the Government absorbs the budgetary impacts of any change in the economy by adjusting expenditure and keeping household income tax rates fixed. This is denoted as GOVBALfx in Table 3. GEXPfx corresponds to results outlined previously in Table 1 where Government consumption is fixed.

Table 3: Sensitivity analysis on public sector budget constraint. Short and Long-run effects of a 5% increase in international exports, BRW closure. In % changes from base year.

	Long-run		Short-run	
	GEXPfx	GOVBALfx	GEXPfx	GOVBALfx
GDP	0.95	1.04	0.19	0.18
CPI	0.75	0.88	1.24	1.31
Total employment	0.75	0.87	0.31	0.30
Real gross wage	0.86	1.01	0.34	0.32
Government consumption	-	0.79	-	-0.24
Government budget	-2.42	-	0.76	-
Total energy use (intermediate+final)	1.72	1.77	1.03	1.12
Energy use in production (total intermediate)	1.41	1.46	0.52	0.56
Energy consumption (total final demand)	2.44	2.49	1.59	1.70
Energy intensity (Total energy use/GDP)	0.76	0.72	0.84	0.93
Total imports	2.77	3.11	3.28	3.48
Total exports	3.63	3.40	2.49	2.39

Focusing on the long run, the binding public sector constraint acts as an additional stimulus in the case of the export demand shock: the stimulus to exports increases income tax revenues which are recycled to increase government current expenditure. The magnitude of the impact of the export stimulus is enhanced compared to the case where Government consumption is fixed. However, the sectoral profile of government expenditure tends to favour comparatively non-traded items e.g. Health, education & defence. We also observe a corresponding increase in prices due to the increase in demand.

As such, competitiveness effects are increased and exports increase by 3.4% as compared to 3.63% in the case where Government consumption is fixed: the additional government spending partially crowds out exports. Although we seek to explore the consequences of fiscal policy changes on energy policy goals both at a national and regional level in more detail in a separate paper, it is evident that Government budget decisions have impacts on energy policy goals. Here energy intensity decrease along with the introduction of the public sector constraint, for example, reflecting the comparatively low energy intensity of public as compared to private consumption.

8. Summary & conclusions

The wider impacts of energy policy on the macro-economy are increasingly recognised in academic and policy discussions around the appropriate use of energy policy. For example, recent analyses on energy efficiency policies emphasise the stimulus to economic activity that these typically generate and their potentially beneficial impacts on distributional issues.

However, the potential impact of economic policies on the energy system have been neglected and, in particular there has been no system-wide analysis of the spillover effects from economic policies to the energy system (Cox et al., 2016). Neglect of such spillovers in the conduct of policy may lead to inefficiencies and undetected conflicts (or complementarities) among energy and economic policy goals. This could be avoided by a more holistic perspective.

We begin by analysing the potential impacts of a successful UK Industrial, business and innovation policy on the UK. In this paper, we analyse the system-wide effects of successful export promotion policies on the energy system. However, since the energy system impacts of such policies are, in large part, transmitted via their impact on the economic system, it is necessary to adopt an approach that fully captures such interdependence. We do so by employing a UK computable general equilibrium (CGE) model, UK-ENVI to analyse the impact of a successful stimulus to exports on the economy and energy sub-systems.

At one level the results of our analysis may be regarded as re-assuring from the perspective of successful UK export promotion policies in that all the major indicators of UK economic activity, including GDP, employment, consumption and investment are typically significantly stimulated. So the major objectives of UK industrial policy are positively impacted by export promotion.

However, there are significant, and typically negative spillover effects to the energy system. Most notably, UK exports are, on average, energy intensive, so that export-driven expansion is associated with a greater stimulus to total energy use than to GDP: the energy intensity of economic activity increases as a result. Furthermore, while not modelled here explicitly, this result could translate into increased CO2 emissions if action is not taken at the same time to decarbonise the economy in line with the Industrial Strategy challenge on Clean Growth. General, across-the-board, export-driven growth is typically not “green” in nature. However, it may be possible to target such policies at specific sectors so as to stimulate “green growth”.

Although we do not attempt to investigate the impacts on precise measures of fuel poverty (or poverty in general) we can identify the impact on the share of households disposable income spent on energy and non-energy goods across income quintiles. Our results suggest that the proportion of the lowest household income group's spending on energy increases so on that basis fuel poverty deteriorates. On the other hand, however, that group's total income and total expenditure on all goods also increase. Other goals of energy policy are similarly adversely affected: affordability (as indicated by the price of energy) declines, although real incomes are actually increasing by more than energy prices so that there is a sense in which "real" affordability is improved.

Energy security is a complex issue with a wide range of indicators (e.g. UK Energy Research Centre, 2018). Here we report that the imported energy to GDP ratio increases. Some would interpret this as a deterioration in security of supply, although that is controversial and imports can and have been used to augment security (e.g. during the miners' strike). Given this we conclude that the impact of export promotion on security of supply is ambiguous (and will vary depending on the source of imports, the routes used to transport them and the mix of sources and fuels). Fuel poverty and affordability indicators noted above can also be included within the energy security framework.

Overall, it is very clear that while successful export growth strategies are likely to have the desired effect on the economy and the stated goals of industrial policy, they could have significant negative spillover effects on the energy system and energy policy goals. Neglecting these spillover effects creates a source of inefficiency in the conduct of effects, and a knowledge of their likely scale, could be used to develop a more holistic, coordinated approach to policy formation and implementation. For example, pursuit of the Clean Growth Strategy could mitigate/offset any increase in emissions that would otherwise result from an export promotion policy. This would minimise the prospect of conflicts between UK industrial and green growth strategies.

Future research should extend this analysis in a number of directions. First, there is the issue of whether other industrial policies have similar impacts on the economy and energy sub-systems. In particular, we shall explore the likely impact of improvements in productivity; another major element of the UK Government's Industrial Strategy. Second, there is the question of whether sectorally-targeted export promotion policies can mitigate the negative spillover effects of export led stimuli, but currently only be by chance that a targeted sector was less energy-intensive than average (since this is not a criterion for targeting). Third, a similar sectorally-targeted analysis should be conducted for productivity growth. Fourth, if the potential gains from coordination of economic and energy policies are to be identified, it is necessary to explore the energy and economy-wide consequences of policies aimed at improving both domestic and industrial energy policy, within a common modelling framework. Ultimately, the framework that we have developed will allow an exploration of the kinds of policy packages that are most likely to facilitate the simultaneous achievement of economic and energy policy goals. This is likely to prove particularly challenging in the context of Brexit.[10]

[10] The likely impacts of Brexit are critically dependent on the precise form of Brexit. See e.g. Dhingra et al (2016), Figus et al (2018b).

Appendices

Appendix A: The mathematical presentation of the UK-ENVI model

Prices

$$PM_{i,t} = \overline{PM}_i \tag{A.1}$$

$$PE_{i,t} = \overline{PE}_i \tag{A.2}$$

$$PQ_{i,t} = \frac{PR_{i,t} \cdot R_{i,t} + PM_{i,t} \cdot M_{i,t}}{R_{i,t} + M_{i,t}} \tag{A.3}$$

$$PIR_{j,t} = \frac{\sum_i VR_{i,j,t} \cdot PR_{j,t} + \sum_i VI_{i,j,t} \cdot \overline{PI}_j}{\sum_i VIR_{i,j,t}} \tag{A.4}$$

$$PY_{j,t} \cdot a_j^Y = \left(PR_{j,t} \cdot (1 - btax_j - sub_j - dep_j) - \sum_i a_{i,j}^V PQ_{j,t} \right) \tag{A.5}$$

$$UCK_t = Pk_t \cdot (r + \delta) \tag{A.6}$$

$$Pc_t^{1-\sigma^c} = \sum_j \delta_j^f \cdot PQ_{j,t}^{1-\sigma^c} \tag{A.7}$$

$$Pg_t^{1-\sigma^g} = \sum_j \delta_j^g \cdot PQ_{j,t}^{1-\sigma^g} \tag{A.8}$$

$$PNE_t = \frac{\sum_z PQ_{z,t} \cdot \bar{V}_z}{\sum_z PQ_z \cdot \bar{V}_z} \tag{A.9}$$

$$PE_t = \frac{\sum_E PQ_{E,t} \cdot \bar{V}_E}{\sum_E PQ_E \cdot \bar{V}_E} \tag{A.10}$$

$$w_t^b = \frac{w_t}{(1 + \tau_t)} \tag{A.11}$$

$$ln\left(\frac{w_t^b}{cpi_t}\right) = b - 0.068\, ln(u_t) + 0.4\, ln\left(\frac{w_{t-1}^b}{cpi_{t-1}}\right) \tag{A.12}$$

$$rk_{j,t} = PY_{j,t} \cdot \delta_j^k \cdot A^{Y\varrho_j} \cdot \left(\frac{Y_{j,t}}{K_{j,t}}\right)^{1-\varrho_j} \tag{A.13}$$

$$Pk_t = \frac{\sum_j PQ_{j,t} \cdot \sum_i KM_{i,j}}{\sum_i \sum_j KM_{i,j}} \tag{A.14}$$

Production technology

$$X_{i,t} = A_i{}^X \cdot \left[\delta_i^Y \cdot Y_{i,t}^{\rho_i^X} + (1-\delta_i^V) \cdot V_{i,t}^{\rho_i^X}\right]^{\frac{1}{\rho_i^X}} \tag{A.15}$$

$$Y_{j,t} = \left(A^{X\rho_j^X} \cdot \delta_j^Y \cdot \frac{PQ_{j,t}}{PY_{j,t}}\right)^{\frac{1}{1-\rho_j^X}} \cdot X_{j,t} \tag{A.16}$$

$$V_{j,t} = \left(A^{X\rho_j^X}(1-\delta_j^V) \cdot \frac{PQ_{j,t}}{Pv_{j,t}}\right)^{\frac{1}{1-\rho_j^X}} \cdot X_{j,t} \tag{A.17}$$

$$V_{j,t} = A^V \cdot \left[\delta_i^V \cdot E_{i,t}^{\rho_i^V} + (1-\delta_i^V) \cdot NE_{i,t}^{\rho_i^V}\right]^{\frac{1}{\rho_i^V}} \tag{A.18}$$

$$\frac{E_{j,t}}{NE_{j,t}} = \left[\left(\frac{\delta_j^V}{(1-\delta_j^V)}\right) \cdot \left(\frac{PNE_t}{PE_t}\right)\right]^{\frac{1}{1-\rho_i^V}} \tag{A.19}$$

$$VV_{z,j,t} = \left(A^{z\rho_j^z}(1-\delta_j^{EN}) \cdot \frac{PNE_t}{PQ_{z,t}}\right)^{\frac{1}{1-\rho_j^Z}} \cdot NE_{j,t} \tag{A.20}$$

$$VV_{E,j,t} = \left(A^{E\rho_j^E}(\delta_j^{EN}) \cdot \frac{PE_t}{PQ_{E,t}}\right)^{\frac{1}{1-\rho_j^E}} \cdot E_{j,t} \tag{A.21}$$

$$Y_{i,t} = A^Y \cdot \left[\delta_i^k \cdot K_{i,t}^{\rho_i^Y} + \delta_i^l \cdot L_{i,t}^{\rho_i^Y}\right]^{\frac{1}{\rho_i^Y}} \tag{A.22}$$

$$L_{j,t} = \left(A^{Y\rho_j^Y} \cdot \delta_j^l \cdot \frac{PY_{j,t}}{w_t}\right)^{\frac{1}{1-\rho_j^Y}} \cdot Y_{j,t} \tag{A.23}$$

Trade

$$VV_{i,j,t} = \gamma_{i,j}^{vv} \cdot \left[\delta_{i,j}^{vm} VM_{i,t}^{\rho_i^A} + \delta_{i,j}^{vir} VIR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.24}$$

$$\frac{VM_{i,j,t}}{VIR_{i,j,t}} = \left[\left(\frac{\delta_{i,j}^{vm}}{\delta_{i,j}^{vir}}\right) \cdot \left(\frac{PIR_{i,t}}{PM_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.25}$$

$$VIR_{i,j,t} = \gamma_{i,j}^{vir} \cdot \left[\delta_{i,j}^{vi} VI_{i,t}^{\rho_i^A} + \delta_{i,j}^{vr} VR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.26}$$

$$\frac{VR_{i,j,t}}{VI_{i,j,t}} = \left[\left(\frac{\delta_{i,j}^{vr}}{\delta_{i,j}^{vi}}\right) \cdot \left(\frac{PI_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.27}$$

$$E_{i,t} = \bar{E}_i \cdot \left(\frac{PE_{i,t}}{PQ_{i,t}}\right)^{\sigma_i^x} \tag{A.28}$$

Regional demand

$$R_{i,t} = \sum_j VR_{i,j,t} + \sum_h QHR_{i,h,t} + QVR_{i,t} + QGR_{i,t} \tag{A.29}$$

Total absorption equation

$$X_{i,t} + M_{i,t} = \sum_j VV_{i,j,t} + \sum_h QH_{i,h,t} + QV_{i,t} + QG_{i,t} + E_{i,t} \tag{A.30}$$

Households and other Domestic Institutions

$$YH_t = (1-\tau_t)L_t^S(1-u_t)w_t + TRF_t + \Pi_t \tag{A.31}$$

$$C_t = YH_t - S_t \tag{A.32}$$

$$W_t = NFW_t + FW_t \tag{A.33}$$

$$NFW_t(1+r_t) = NFW_{t+1} + (1-\tau_t)L_t^s\,(1-u_t)w_t + Trf_t \tag{A.34}$$

$$FW_t(1+r_t) = FW_{t+1} + \Pi_t - S_t \tag{A.35}$$

$$Trf_t = Pc_t \cdot \overline{Trf} \tag{A.36}$$

$$S_t = mps \cdot [(1-\tau_t)L_t^s\,(1-u_t)w_t + Trf_t] \tag{A.37}$$

$$\Pi_t = d^h \cdot \sum_i rk_{i,t}K_{i,t} \tag{A.38}$$

$$C_t = [\delta^E(\gamma Ec_t)^{\rho e} - (1-\delta^E)NEc_t^{\rho e}]^{\frac{1}{\rho e}} \tag{A.39}$$

$$Ec_t = \left[\gamma^{\rho e}\,\delta^E \cdot \left(\frac{Pc_t}{PE_t}\right)\right]^{\frac{1}{1-\rho e}} C_t \tag{A.40}$$

$$Ec_t = [\delta^{co}CO_t^{\rho_g} - (1-\delta^{co})EG_t^{\rho_g}]^{\frac{1}{\rho_g}} \tag{A.41}$$

$$\frac{CO_t}{EGc_t} = \left[\left(\frac{\delta^{co}}{1-\delta^{co}}\right)\cdot\left(\frac{PEG_t}{PCO_t}\right)\right]^{\frac{1}{1-\rho_g}} \tag{A.42}$$

$$QH_{z,t} = \delta_z^{f\,\rho_i^c}\cdot\left(\frac{Pc_t}{PQ_{z,t}}\right)^{\rho_i^c}\cdot NEc_t \tag{A.43}$$

$$EG_t = \left[\delta^{Ele}Ele_t^{\rho_{el}} - (1-\delta^{el})GAS_C^{\rho_{el}}\right]^{\frac{1}{\rho_{el}}} \tag{A.44}$$

$$\frac{Ele_t}{GAS_t} = \left[\left(\frac{\delta^{GAS}}{1-\delta^{GAS}}\right)\cdot\left(\frac{PQ_{GAS,t}}{PQ_{Ele,t}}\right)\right]^{\frac{1}{1-\rho_{el}}} \tag{A.45}$$

$$QH_{ele,t} = Ec_t \tag{A.46}$$

$$QH_{GAS,t} = GAS_t \tag{A.47}$$

$$QH_{coal,t} = CL_t \tag{A.48}$$

$$QH_{oil,t} = OIL_t \tag{A.49}$$

$$QH_{i,t} = \gamma_i^f\cdot\left[\delta_i^{hir}\cdot QHIR_{i,t}^{\rho_i^A} + \delta_i^{hm}\cdot QHM_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.50}$$

$$\frac{QHIR_{i,t}}{QHM_{i,t}} = \left[\left(\frac{\delta_i^{hir}}{\delta_i^{hm}}\right)\cdot\left(\frac{PM_{i,t}}{PIR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.51}$$

$$QHIR_{i,t} = \gamma_i^{fir}\cdot\left[\delta_i^{hr}\cdot QHR_{i,t}^{\rho_i^A} + \delta_i^{hi}\cdot QHI_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.52}$$

$$\frac{QHR_{i,t}}{QHI_{i,t}} = \left[\left(\frac{\delta_i^{hr}}{\delta_i^{hi}}\right)\cdot\left(\frac{PI_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.53}$$

Government

$$FD_t = G_tPg_t + \sum_{dngins} TRG_{dngins,t}\cdot Pc_t - \left(d^g\cdot\sum_i rk_{i,t}\cdot K_{i,t} + \sum_i IBT_{i,t} + \tau_t\cdot\sum_j L_{j,t}\cdot w_t \; + \overline{FE}\cdot\varepsilon_t\right) \tag{A.54}$$

$$QG_{i,t} = \delta_i^g\cdot G_t \tag{A.55}$$

$$QGR_{i,t} = QG_{i,t};\ QGM_{i,t} = 0 \tag{A.56}$$

Investment Demand

$$QV_{i,t} = \sum_{j} KM_{i,j} \cdot J_{j,t} \tag{A.57}$$

$$QV_{i,t} = \gamma_i^{v} \cdot \left[\delta_i^{qvm} \cdot QVM_{i,t}^{\rho_i^A} + \delta_i^{qvir} \cdot QVIR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.58}$$

$$\frac{QVM_{i,t}}{QVIR_{i,t}} = \left[\left(\frac{\delta_i^{qvm}}{\delta_i^{qvir}}\right) \cdot \left(\frac{PIR_{i,t}}{PM_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.59}$$

$$QVIR_{i,t} = \gamma_i^{vir} \cdot \left[\delta_i^{qvi} \cdot QVI_{i,t}^{\rho_i^A} + \delta_i^{qvr} \cdot QVR_{i,t}^{\rho_i^A}\right]^{\frac{1}{\rho_i^A}} \tag{A.60}$$

$$\frac{QVR_{i,t}}{QVI_{i,t}} = \left[\left(\frac{\delta_i^{qvr}}{\delta_i^{qvi}}\right) \cdot \left(\frac{PI_{i,t}}{PR_{i,t}}\right)\right]^{\frac{1}{1-\rho_i^A}} \tag{A.61}$$

Time path of investment

$$I_{i,t} = v \cdot \left(KS_{i,t}^{*} - KS_{i,t}\right) \cdot \delta KS_{i,t} \tag{A.62}$$

$$KS_{i,t}^{*} = \left(A^{Y} \quad {}^{\rho_j^Y} \cdot \delta_j^{k} \cdot \frac{PY_{j,t}}{rk_{j,t}}\right)^{\frac{1}{1-\rho_j^Y}} \cdot Y_{j,t} \tag{A.63}$$

Factors accumulation

$$KS_{i,t+1} = (1-\delta) \cdot KS_{i,t} + I_{i,t} \tag{A.64}$$

$$K_{i,t} = KS_{i,t} \tag{A.65}$$

$$LS_t \cdot (1-u_t) = \sum_{j} L_{j,t} \tag{A.66}$$

Indirect taxes and subsidies

$$IBT_{i,t} = btax_i \cdot X_{i,t} \cdot PQ_{i,t} \tag{A.67}$$

Total demand for import and current account

$$M_{i,t} = \sum_j VI_{i,j,t} + \sum_j VM_{i,j,t} + \sum_h QHM_{i,h,t} + QGM_{i,t} + QVI_{i,t} + QVM_{i,t} \tag{A.68}$$

$$TB_t = \sum_i M_{i,t} \cdot PM_{i,t} - \sum_i E_{i,t} \cdot PE_{i,t} + \varepsilon \cdot \left(\sum_{dngins} \overline{REM}_{dngins} + \overline{FE} \right) \tag{A.69}$$

Steady State conditions

$$\delta \cdot KS_{i,T} = I_{i,T} \tag{A.70}$$

$$R^k_{i,T} = \lambda_{i,T}(r + \delta) \tag{A.71}$$

$$FD_T = -\left[r + \left(\frac{Pc_{t+1}}{Pc_t} - 1 \right) \right] \cdot Pg_T \cdot GD_T \tag{A.72}$$

$$TB_T = -r \cdot D_T \tag{A.73}$$

$$NFW_t r = (1 - \tau_t) L^s_t \, (1 - u_t) w_t + Trf_t \tag{A.74}$$

$$FW_t \cdot r_T = \Pi_t - S_t \tag{A.75}$$

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

$$KS_{i,t=1} = KS_{i,t=0} \tag{A.76}$$

$$LS_{=1} = LS_{t=0} \tag{A.77}$$

Glossary

i,j (*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-gov institutions
E ($\subset i$)	the set of energy sectors {*Coal, Ele, Gas and Oil*}
z ($\subset i$)	the set of non-energy sectors

Prices

$PY_{i,t}$	value added price
$PR_{i,t}$	regional price
$PQ_{i,t}$	output price
$PIR_{i,t}$	national commodity price (regional + ROI)
$PI_{i,t}$	price of RUK commodities
$rk_{i,t}$	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
Pg_t	aggregate price of Government consumption goods
ε	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
$VV_{i,j,t}$	total intermediate inputs in *i* and *j*
$V_{i,t}$	Total intermediate inputs in *i*
$VR_{i,j,t}$	regional intermediate inputs
$VM_{i,j,t}$	ROW intermediate inputs
$VIR_{i,j,t}$	national intermediate inputs (ROW+RUK)
$VI_{i,j,t}$	ROI intermediate inputs
$G_{i,t}$	aggregate government expenditure
$QG_{i,t}$	total government expenditure by sector *i*
$QGR_{i,t}$	regional government expenditure
$QGM_{i,t}$	government expenditure(ROI+ROW)
C_t	aggregated household consumption
Ec_t	household consumption of energy
NEc_t	household consumption of non-energy goods and motive energy
CO_t	household consumption of Coal
EG_t	household consumption of Electricity and Gas
Ele_t	household consumption of Electricity
GAS_t	household consumption of Gas
CL_t	household consumption of Coal
$QH_{i,t}$	total households consumption in sector *i*
$QHR_{i,t}$	regional consumption in sector *i*
$QHIR_{i,t}$	regional+RUK consumption in sector *i*
$QHM_{i,t}$	import consumption in sector *i*
$QV_{i,t}$	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 (Regional+RUK)
$QVI_{i,t}$	ROI investment demand

$I_{j,t}$	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
S_t	domestic non-government saving
Trf_t	households net transfer
$TRSF_{dngins,dnginsp,t}$	transfer among *dngins*
$HTAX_t$	total household tax
TB_t	current account balance

Exogenous variables

$\overline{REM}_t$	remittance for *dngins*
$\overline{FE}_t$	remittance for the Government
$GSAV_t$	government saving
r	interest rate

Elasticities

σ	constant elasticity of marginal utility
ρ^X_i	elasticity parameter between intermediate inputs and value added
ρ^Y_i	elasticity parameter between capital and labour
ρ^A_i	in Armington function
σ^x_i	of export with respect to term of trade
σ^e_i	Substitution between energy and non-energy in Household consumption
σ^g_i	Substitution elasticity between CO and EG in Household consumption
σ^o_i	Substitution elasticity between Coal and Oil in Household consumption

Parameters

$a^V_{i,j}$	Input-output coefficients for *i* used in *j*
a^Y_j	share of value added on production

$\delta_j^{Y,V}$	shares in CES output function in sector *j*
$\delta_j^{k,l}$	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
$\delta_{i,h}^{E,co,cl}$	shares parameters in CES function for households consumption
$\delta_{i,h}^{hr,hm}$	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
$btax_i$	rate of business tax
$KM_{i,j}$	physical capital matrix
mps	rate of saving in institutions *dngins*
τ	rate of income tax
ρ	pure rate of consumer time preference
bb	rate of distortion or incentive to investment
δ	rate of depreciation
γ	efficiency shock in household consumption

Appendix B: Sector characteristics by income and expenditure components, 2010 UK Social Accounting Matrix

		% share of costs (expenditures)						% share of incomes (receipts)					
		Activities	Energy (2,3,4,9,16 and 17)	Labour	OVA	Taxes on expenditures	ROW imports	Activities	Households	Government	Capital formation	Stock	ROW exports
1.AGR	Agriculture, forestry & fishing	47	3	17	31	-9	14	54	32	0	4	0	10
2. MIN	Mining & quarrying	47	17	28	7	5	13	97	30	0	0	-36	8
3. CRU	Crude Petroleum + Natural Gas & Metal Ores + coal	26	12	7	61	1	5	46	4	0	1	-1	49
4. OMI	Other Mining & mining services	33	9	17	36	2	11	54	7	1	1	0	37
5. FOO	Food (+ Tobacco)	57	3	23	5	1	15	50	35	1	0	0	14
6. DRI	Drink	57	4	17	15	2	8	50	22	0	0	1	27
7. TEX	Textile, Leather & Wood	35	2	28	10	1	26	55	13	1	4	0	28
8. PAP	Paper & Printing	37	5	28	11	2	23	70	15	1	3	0	10
9. COK	Coke & refined petroleum products	21	15	10	3	5	62	34	25	0	0	0	41
10. CHE	Chemicals & Pharmaceuticals	34	3	17	17	1	30	28	3	0	1	0	68
11. RUB	Rubber, Cement, + Glass	37	6	28	7	2	26	73	2	0	1	1	24
12. IRO	Iron, steel + metal	37	3	27	6	2	29	64	2	0	5	3	26
13. ELM	Electrical Manufacturing	40	2	30	10	1	20	36	4	0	11	1	48
14. MOT	Manufacture of Motor Vehicles, Trailers & Semi-Trailers	53	1	18	5	1	23	24	13	0	2	1	60
15. TRA	Transport equipment + other Manufacturing (incl Repair)	47	2	27	7	1	18	40	8	1	9	0	43

Appendix B continued:

16. ELE	Electricity, transmission & distribution	67	53	6	11	2	14	67	30	1	1	0	2
17. GAS	Gas; distribution of gaseous fuels through mains; steam & air conditioning	57	45	10	12	3	18	56	44	0	0	0	0
18. WTR	Natural water treatment & supply services; sewerage services	29	4	20	43	5	2	31	69	0	0	0	0
19.WAM	Water Management & remediation	50	1	21	16	6	7	38	13	25	2	0	22
20. CON	Construction - Buildings	49	1	22	19	3	7	47	1	0	52	-1	1
21.WHO	Wholesale & Retail Trade	39	2	35	15	4	7	24	57	1	3	0	16
22. TRL	Land Transport	43	3	35	12	2	8	53	40	1	1	0	4
23. TRO	Other transport	46	2	23	9	3	19	12	53	0	0	0	34
24. TRS	Transport support	52	1	33	7	3	5	86	4	1	0	0	9
25. ACC	Accommodation & Food Service Activities	35	1	32	12	8	13	13	72	1	2	0	12
26. COM	Communication	32	1	35	20	2	12	50	25	2	11	0	12
27. SER	Services	35	1	23	33	2	6	45	37	0	3	0	16
28. EDU	Education health & defence	29	1	49	6	5	11	16	14	68	1	0	1
29. REC	Recreational	35	1	28	24	5	8	28	50	5	4	0	14
30. OTR	Other private services	22	1	47	21	4	6	37	43	4	8	0	8

Appendix C: Long-run effects on individual sectors of a 5% increase in international exports, BRW closure. In % changes from base year

	Total output	Output price	Employment	Value added	Total import	Total export	Capital stock	Investment	Households consumption	Energy use in production
1. AGR	1.18	0.62	0.88	1.05	2.49	3.71	1.15	1.15	1.17	1.23
2. MIN	1.22	0.70	0.95	1.00	5.73	3.54	1.22	1.22	1.22	1.30
3. CRU	2.42	0.45	2.07	2.31	2.69	4.06	2.34	2.34	1.20	2.42
4. OMI	2.42	0.63	2.12	2.31	3.30	3.69	2.40	2.40	1.18	2.48
5. FOO	1.21	0.65	0.92	0.97	2.51	3.64	1.19	1.19	1.15	1.27
6. DRI	1.60	0.59	1.29	1.41	2.29	3.78	1.56	1.56	1.16	1.64
7. TEX	1.65	0.65	1.36	1.43	2.87	3.65	1.63	1.63	1.18	1.71
8. PAP	0.95	0.64	0.66	0.74	2.41	3.67	0.93	0.93	1.18	1.01
9. COK	2.36	0.32	1.96	2.03	2.80	4.33	2.24	2.24	1.27	2.32
10. CHE	3.10	0.48	2.75	2.89	3.19	4.00	3.03	3.03	1.21	3.11
11. RUB	1.56	0.65	1.27	1.32	2.82	3.66	1.54	1.54	1.17	1.62
12. IRO	1.90	0.55	1.58	1.62	2.94	3.85	1.85	1.85	1.19	1.93
13. ELM	2.36	0.64	2.07	2.14	3.08	3.66	2.35	2.35	1.18	2.43
14. MOT	2.89	0.56	2.57	2.62	3.38	3.84	2.84	2.84	1.22	2.92
15. TRA	2.15	0.64	1.86	1.91	2.87	3.67	2.13	2.13	1.18	2.22
16. ELE	1.06	0.43	0.70	0.88	2.27	4.10	0.98	0.98	1.31	1.06
17. GAS	1.03	0.46	0.68	0.83	2.46	4.05	0.96	0.96	1.31	1.04
18. WTR	0.81	0.66	0.53	0.71	2.48	3.62	0.80	0.80	1.13	0.88
19. WAM	1.11	0.75	0.85	0.96	2.54	3.44	1.12	1.12	1.11	1.20
20. CON	0.92	0.71	0.65	0.78	2.67	3.53	0.92	0.92	1.12	1.00
21. WHO	1.27	0.77	1.02	1.10	3.01	3.39	1.29	1.29	1.15	1.37
22. TRL	0.90	0.79	0.65	0.72	2.81	3.36	0.93	0.93	1.16	1.01
23. TRO	1.78	0.71	1.51	1.58	3.18	3.52	1.78	1.78	1.19	1.87
24. TRS	1.10	0.82	0.86	0.90	2.93	3.31	1.13	1.13	1.17	1.21
25. ACC	1.11	0.77	0.85	0.93	2.96	3.40	1.13	1.13	1.17	1.21
26. COM	1.08	0.78	0.83	0.93	2.80	3.38	1.10	1.10	1.16	1.18
27. SER	1.29	0.71	1.02	1.18	2.66	3.52	1.29	1.29	1.15	1.37
28. EDU	0.10	1.09	-0.05	-0.02	2.81	2.75	0.22	0.22	1.10	0.30
29. REC	1.15	0.76	0.89	1.02	2.76	3.43	1.17	1.17	1.16	1.25
30. OTR	0.88	0.87	0.66	0.75	2.88	3.19	0.94	0.94	1.14	1.01

Appendix D: Sensitivity analysis on Armington trade elasticities. Short and Long-run effects of a 5% increase in international exports, BRW closure. In % changes from base year.

	Long-run			Short-run		
	σ = 1.5	σ = 2	σ = 2.5	σ = 1.5	σ = 2	σ = 2.5
GDP	1.01	0.95	0.90	0.21	0.19	0.17
CPI	0.80	0.75	0.70	1.35	1.24	1.15
Unemployment rate (pp difference)	-0.75	-0.71	-0.67	-0.32	-0.29	-0.27
Total employment	0.80	0.75	0.71	0.34	0.31	0.29
Nominal gross wage	1.72	1.61	1.52	1.72	1.58	1.46
Real gross wage	0.92	0.86	0.81	0.37	0.34	0.31
Households wealth	1.13	1.06	1.00	0.60	0.55	0.51
Households consumption	1.23	1.16	1.09	0.78	0.75	0.73
Labour income	2.53	2.38	2.24	2.07	1.90	1.75
Capital income	2.11	1.99	1.88	3.08	2.83	2.61
Government budget	-2.56	-2.42	-2.29	0.86	0.76	0.69
Investment	1.35	1.28	1.21	2.05	2.01	1.96
Total energy use (intermediate+final)	1.79	1.72	1.66	1.06	1.03	1.00
- Electricity	1.36	1.26	1.18	0.88	0.81	0.75
- Gas	1.44	1.35	1.27	0.74	0.70	0.66
Energy use in production (total intermediate)	1.51	1.41	1.33	0.58	0.52	0.47
Energy consumption (total final demand)	2.47	2.44	2.42	1.53	1.59	1.65
- Households	1.38	1.30	1.22	0.94	0.92	0.89
- Investment	1.35	1.26	1.17	1.54	1.40	1.28
- Exports	4.04	4.11	4.16	2.35	2.55	2.73
Energy output prices	0.53	0.50	0.47	1.16	1.06	0.97
Energy output	1.74	1.65	1.56	0.53	0.47	0.41
Non energy output	1.19	1.13	1.07	0.52	0.48	0.45
Energy intensity (Total energy use/GDP)	0.77	0.76	0.75	0.85	0.84	0.82
Total imports	2.66	2.77	2.86	3.06	3.28	3.45
Total exports	3.54	3.63	3.71	2.29	2.49	2.66
Net exports (exports-imports)	-0.04	-0.04	-0.03	0.09	0.09	0.09
- Electricity	2.23	2.27	2.30	2.29	2.41	2.48
- Gas	2.43	2.46	2.49	2.61	2.70	2.77

Appendix E: Sensitivity analysis on public sector budget constraint. Short and Long-run effects of a 5% increase in international exports. In % changes from base year.

	Long-run			Short-run			
	FRW-FNW	BRW	ELS	FNW	FRW	BRW	ELS
GDP	3.28	1.04	0.23	0.85	0.35	0.18	-
CPI	-	0.88	1.20	1.18	1.37	1.31	1.33
Unemployment rate (pp difference)	-3.09	-0.82	-	-1.31	-0.54	-0.28	-
Total employment	3.29	0.87	-	1.39	0.58	0.30	-
Nominal gross wage	-	1.89	2.59	-	1.37	1.64	2.06
Real gross wage	-	1.01	1.38	-1.16	-	0.32	0.72
Households wealth	2.25	1.21	0.84	0.57	0.60	0.55	0.54
Households consumption	2.37	1.31	0.94	1.39	1.22	0.96	0.83
Labour income	3.29	2.78	2.59	1.40	1.96	1.94	2.06
Capital income	3.28	2.14	1.73	4.89	3.66	2.99	2.45
Government consumption	3.42	0.79	-0.16	0.35	-0.11	-0.24	-0.39
Government budget	-	-	-	-	-	-	-
Investment	3.28	1.31	0.61	4.51	3.25	2.19	1.44
Total energy use (intermediate+final)	3.31	1.77	1.22	1.70	1.35	1.12	0.94
- Electricity	2.99	1.35	0.76	1.74	1.27	0.92	0.69
- Gas	2.90	1.45	0.94	1.23	0.98	0.80	0.67
Energy use in production (total intermediate)	3.26	1.46	0.81	1.03	0.71	0.56	0.42
Energy consumption (total final demand)	3.26	1.46	0.94	1.89	1.82	1.70	1.64
- Households	2.32	1.48	1.18	1.45	1.37	1.13	1.03
- Investment	3.16	1.29	0.62	3.25	2.30	1.61	1.10
- Exports	5.00	3.96	3.58	2.47	2.44	2.50	2.52
Energy output prices	-	0.58	0.80	1.06	1.13	1.10	1.10
Energy output	3.36	1.65	1.04	0.84	0.62	0.51	0.42
Non energy output	3.31	1.23	0.48	1.16	0.68	0.49	0.30
Energy intensity (Total energy use/GDP)	0.02	0.72	0.98	0.95	0.99	0.93	-
Total imports	3.14	3.11	3.11	4.03	3.91	3.48	3.28
Total exports	5.00	3.40	2.83	2.61	2.29	2.39	2.35
Net exports (exports-imports)	-0.10	0.01	0.05	0.14	0.16	0.11	0.10
- Electricity	3.11	2.50	2.28	3.18	2.90	2.57	2.39
- Gas	3.17	2.70	2.53	3.44	3.20	2.88	2.71

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