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THE ECONOMIC IMPACTS OF UK LABOUR PRODUCTIVITY-ENHANCING INDUSTRIAL POLICIES AND THEIR SPILLOVER EFFECTS ON THE ENERGY SYSTEM

BY

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The economic impacts of UK labour productivity-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 literature. But this interdependence similarly implies that policy interventions in the non-energy system also affect the energy system, though such spill-overs have not been extensively researched. Increasing labour productivity is a key component of the UK's Industrial Strategy. The present paper analyses the impacts of success in this policy on key elements of the economic and energy systems through simulation. It uses a UK computable general equilibrium (CGE) model - UK-ENVI – to fully capture economy/energy interdependence. The simulation results suggest that there are trade-offs, particularly between achieving energy and economic policy goals. For example, increased labour productivity stimulates GDP but also energy use and territorial industrial CO_2 emissions, whilst reducing short-run employment. Policy makers should therefore be aware that successfully implementing the Industrial Strategy might impact on the UK's Clean Growth Strategy and on the goals of energy policy more generally. Knowledge of the nature and scale of economy/energy spill-overs potentially improves policy co-ordination and over-all effectiveness. For example, this analysis reveals the extent of energy policy adjustment that would be required to accompany a successful industrial policy in order to maintain a given level of emissions.

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Key words: energy policy, industrial strategy, labour productivity

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1. Introduction

The economic and energy systems are inextricably linked so that any changes in the economy also affect energy use. Clear evidence is provided by the great recession where between 2008 and 2009 a 4% contraction in the UK economy was accompanied by a 6% fall in total UK energy use (UK Government, 2017a). However, these interactions do not necessarily produce counteracting policy effects; under certain circumstances "double dividends" or even "multiple benefits" are available. In particular, policies might stimulate economic activity whilst simultaneously reducing emissions and potentially contribute to achieving wider policy goals. Although there is general recognition of this interdependence, ex-ante and ex-post assessments of the likely effects of economic policies, such as industrial and fiscal policy, typically fail to incorporate the impact on energy use/emissions. Rather these assessments focus overwhelmingly on the policies' primary economic objectives, such as Gross Domestic Product (GDP) growth and employment creation. However, neglect of the energy-use implications of non-energy policies is likely to lead to inefficiencies in their design and implementation (Royston et al., 2018). The practical importance of this depends on the strength and nature of the interdependencies between economic and energy systems.

A review by Cox et al. (2016) points to a lack of research concerning the impacts of economic policies on the energy system; less than 10% of the research papers considered (49 out of 576) investigated this issue and only 25 of these focus specifically on the UK. The smallest number of dedicated analyses was found in research relating to communications, culture and sport, education, health, industry and international trade; the greatest, within the UK-focused literature, concerned 'planning policy' and 'work policy'. Cox et al. (2016) notes these research papers' concentration on single aspects of the energy system, such as disposable income spent on fuel and passenger miles travelled, and the lack of system-wide approaches that link these elements together. Their literature review concludes that future work should cover all energy/non-energy interactions in a system-based, comparative and multi-scalar manner.

However, changes in energy use driven purely by economic policies have not been totally ignored. An example is research into the Environmental Kuznets Curve. This posits that rising prosperity will ultimately be accompanied by falling pollution, following an earlier period in which growth is accompanied by increasing pollution. Examples include Grossman and Kreuger (1995), Jaffe et al. (2003), Vollebergh et al. (2009) and Cui et al. (2017).

We approach this broad issue through multi-sectoral computable general equilibrium (CGE) simulation. Such methods are common and can be employed to develop a more holistic perspective on the conduct of policy (see Bergman, 2005, for a review). The intention in the present paper is to create a framework that explicitly recognises, and seeks to quantify, the scale of spill-overs from economic and energy policies to energy and economic policy goals. Where these spill-overs prove significant, better coordination of economic and energy policies would improve the outcomes for both. This analysis therefore has two objectives: to explore how economic policies impact key elements of the energy system; and to demonstrate the value of CGE modelling in capturing and quantifying these interdependencies.

Key pillars of the UK Industrial Strategy concern 'encouraging trade' and 'boosting productivity' (UK Government, 2017b). Ross et al., (2018) explores the likely impact of export promotion; the present paper analyses the effects of increased labour productivity and specifically the comparatively unexplored impacts of economic policies on energy policy indicators and goals, such as reducing energy use, energy intensity and emissions. Since the impacts of industrial policies are, in large part, transmitted via the economic system, economic/environment interaction has to be fully captured.

This paper is organised as follows. Section 2 provides a brief overview of the UK's industrial strategy. Section 3 outlines an ex-ante analysis of an increase in labour productivity. Section 4 describes the structure of our UK energy-economy-environment model, paying particular attention to the linkages between the non-energy and energy components. Section 5 gives the simulation strategy. Results are presented in Sections 6 and 7, and brief conclusions in Section 8.

2. UK Industrial Strategy

The UK Government's present Industrial Strategy aims at 'creating an economy that boosts productivity and earning power throughout the UK' (UK Government, 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). It 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) (UK Government, 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 the data revolution (how to embed and maximise the advantages of AI and data), and dealing with an aging society (healthcare and labour market challenges) (UK Government, 2017b). Increasing productivity is a key objective of the Government's strategy with current research strongly suggesting that productivity growth will be necessary for sustainable improvements in living standards.

In practice productivity interventions will involve sectoral targeting which is likely to significantly influence the impact on both the economic and energy sub-systems. For example, individual industries, such as construction, which tend to be targeted by such interventions. Moreover, there are a number of other factor-augmenting productivity policies that could be considered. We shall, in due course, explore the transmission mechanisms of productivity-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 discuss how the success of these policies will be measured in terms of scale of impacts, time-frames or the precise policy instruments used. We therefore here simply simulate the impacts of a successful policy that enhances labour productivity across the board equally to all sectors".

Despite being concerned with coordinating policy, the Industrial Strategy does not explicitly consider trade-offs between, or complementarities across, policies and how such tensions and conflicting

demands could be overcome. As we illustrate in theoretical and empirical analysis, increasing productivity has a significant impact on key elements of the energy system and therefore on the achievement of energy policy goals.

3. Ex-ante labour market analysis of a labour productivity stimulus

Improved labour efficiency is a key element of UK industrial policy whose aim is to increase GDP. However, we are also interested here in the spillover effects which impact other economic and energy policy objectives; in particular employment and energy use. One direct effect of an improvement in labour efficiency is that it allows the same level of labour services (measured in efficiency units) to be supplied by fewer workers. This has a negative impact on employment. But improved efficiency also reduces the cost of production, enhances competitiveness and thereby leads to an expansion in output, increasing the derived demand for both energy and labour as inputs. Increased labour productivity also generally leads to some substitution of labour, measured in efficiency units, for energy in production. However, additionally, changes in the level of employment also affect household income, which will subsequently impact on the household energy consumption.

Clearly, successful industrial policies to improve labour productivity set up a complex set of endogenous economic responses which will also affect the levels of employment and energy use. In this section, we present a stylised, stripped-down model of a very basic economy so as to identify key parameter values that determine the qualitative and quantitative changes in these variables that accompany increased labour productivity. Results from this analysis are used to aid interpretation of the simulation outcomes reported in Section 6 from a CGE model which incorporates substantial additional economic detail.

In the basic analytical model the output of the production sector, which is all exported, is generated using only two inputs, labour and energy. All energy is imported. The industrial sector operates under perfect competition so that there are zero profits. Wages are the sole component of GDP and household income, which is spent on energy and an imported consumption good. The prices of energy, the imported consumption good and labour are fixed. The produced export good faces a conventional demand curve so that its price falls as output rises. Essentially these assumptions allow production to be treated as though it were in partial equilibrium whilst making household income endogenous.

Equation (1) expresses the proportionate change in total energy use, $\dot{e}^T$, as the weighted sum of the proportionate increase in energy use in production, $\dot{e}^P$, and in the associated proportionate increase in employment, $\dot{l}$, which generates increased direct household consumption of energy.

$$\dot{e}^T = \frac{\Delta e^T}{e_0^T} = \omega \dot{e}^P + (1-\omega)\dot{l} \qquad (1)$$

In expression (1), ω is the share of energy total use that is used in production, where:

$$0 < \omega = \frac{(1-s)}{1-(1-\beta)s} < 1 \qquad (2)$$

with s the share of labour in output in period zero and β the share of consumption expenditure going to energy. Expressions (1) and (2) are derived In Appendix 1.

In this paper, one major concern is $\Gamma_{\gamma}^{e^T}$, the elasticity of total energy use with respect to the efficiency of labour in production, γ. This is defined as the proportionate change in total energy use divided by the proportionate change in labour efficiency. It is important to be clear from the start as to what is meant by an improvement in labour efficiency here. Both in this section and in the simulations reported in Sections 6 and 7 a labour efficiency improvement implies an increase solely in the effectiveness of the labour input in production with the effectiveness of the energy input remaining unchanged. That is to say, after a 10% increase in labour efficiency, for example, the same level of output could be produced using the same energy input but 10% less physical labour.[1]

The elasticity of total energy use with respect to labour efficiency can be found by differentiating equation (1), which gives:

$$\Gamma_{\gamma}^{e^T} = \frac{\delta \dot{e}^T}{\delta \gamma} = \omega \frac{\delta \dot{e}^P}{\delta \gamma} + (1-\omega)\frac{\delta \dot{l}}{\delta \gamma} = \omega \Gamma_{\gamma}^{e^p} + (1-\omega)\Gamma_{\gamma}^{l} \tag{3}$$

In equation (3), $\Gamma_{\gamma}^{e^p}$ and Γ_{γ}^{l} are, in order, the elasticities of energy in production and employment, both with respect to a change in labour efficiency. Using results given in Figus and Swales (2018), these input-use elasticities can be obtained as functions whose arguments are the elasticity of demand for the product, η, the elasticity of substitution between labour and energy in production, σ, and the share of labour in production, s:

$$\Gamma_{\gamma}^{e^p} = \frac{\delta \dot{e}^P}{\delta \gamma} = s(\eta - \sigma) \tag{4}$$

$$\Gamma_{\gamma}^{l} = \frac{\delta \dot{l}}{\delta \gamma} = \sigma(1-s) + s\eta - 1 \tag{5}$$

Substituting equations (4) and (5) into (3) and simplifying produces equation (6). Here the elasticity of total energy use with respect to a change in labour efficiency is given as a function of the demand and production substitution parameters η and σ, and the share parameters, s and β:

$$\Gamma_{\gamma}^{e^T} = s\eta - \left[\omega s - (1-\omega)(1-s)\right]\sigma - (1-\omega) \tag{6}$$

Where, using equation (2), $\omega s - (1-\omega)(1-s) = \frac{(1-s)s(1-\beta)}{1-(1-\beta)s} > 0$.

3.1. Key elasticities

Equations (4), (5) and (6) are central for the analysis in identifying the reaction of the three key variables e^T, e^P and l to increased labour efficiency. Although it is apparent from equation (6) that the share

[1] If the labour input is measured in efficiency units, l^e, then $l^e = l(1+\gamma)$. This is what Gilingham et al. (2014) refers to, when dealing with an increase in energy efficiency, as a zero cost breakthrough. For a more detailed treatment in a partial equilibrium setting see Figus and Swales (2018).

parameters s and β figure too, the subsequent focus will primarily be on the roles played by the elasticity of demand for the product, η, and the elasticity of substitution in production, σ.

We begin by considering the situation where these elasticities are both zero, so that $\eta, \sigma = 0$. This is a case where product demand is completely price inelastic and the production function is Leontief, so that there are no substitution possibilities between inputs. This implies fixed coefficients in production and would correspond to a very rudimentary Input-Output (IO) system. An increase in labour efficiency in this case simply reduces the labour input per unit of output whilst the energy input per unit output and total output remain constant. There is no change in energy use in production, but employment, the total wage bill and therefore also total household income and total energy use falls: $\Gamma_{\gamma}^{e^p} = 0$ and $\Gamma_{\gamma}^{l}, \Gamma_{\gamma}^{e^T} < 0$.

However, where η and σ are greater than zero the labour and energy use will be further affected by endogenous changes in output and input intensity, as well as consumption. Specifically, differentiating equations (4), (5) and (6) with respect to η gives $\frac{\delta\Gamma_{\gamma}^{e^p}}{\delta\eta}, \frac{\delta\Gamma_{\gamma}^{e^T}}{\delta\eta}, \frac{\delta\Gamma_{\gamma}^{l}}{\delta\eta} > 0$: the more elastic the demand for the product, the more likely an increase in labour efficiency will increase both energy use and employment. This is because the positive output effect that accompanies improved competitiveness increases with a higher demand elasticity. On the other hand, the greater is the elasticity of substitution, the more likely that labour use will rise and that energy use in production and total energy use will fall as labour productivity increases. Differentiating with respect to σ gives: $\frac{\delta\Gamma_{\gamma}^{e^p}}{\delta\sigma}, \frac{\delta\Gamma_{\gamma}^{e^T}}{\delta\sigma} < 0$ and $\frac{\delta\Gamma_{\gamma}^{l}}{\delta\sigma} > 0$. In this case the change in total energy use is subject to conflicting effects. Increasing σ leads to greater substitution of labour for energy in production, which has a negative impact on energy use. On the other hand, the subsequent expansion in employment has a positive household income effect in consumption. However, the negative substitution effect on energy use is always dominant with an increase in σ.

3.2. Zero elasticity of employment, production energy and total energy use

It is clear that the values taken by the parameters η and σ affect both the sign and magnitude of the changes to employment and energy use. It is pedagogically useful to construct a diagram in η and σ space to identify those sets of parameter values where such changes are positive or negative, subsequent to an improvement in labour efficiency.[2] Setting $\Gamma_{\gamma}^{e^p} = 0$ in equation (4) produces:

$$s(\eta - \sigma) = 0 \rightarrow \eta = \sigma \qquad (7)$$

In Figure 1, equation (7) is represented by the line 0AE which is a 45 degree line through the origin. This gives the values of η and σ where a change in labour efficiency produces no change in the use of energy in production. Combinations of η and σ above and to the left of that line generate increased energy

[2] Comparable analysis for the energy and labour use in production, in a slightly different context, is employed in Figus and Swales (2018).

use in production in response to increased labour efficiency; points below and to the right produce reductions. As a result of higher labour productivity, the rise in output, through increased competitiveness, has a positive impact on energy use in production. However, the reduction in the price of labour inputs, measured in efficiency units, will lead to a less energy intensive production process, as firms substitute labour for energy. Where the elasticity of demand for the product just equals the elasticity of substitution in production these two forces precisely cancel. However, where one is greater than the other, the total energy use in production will change either positively where η (or negatively where σ) has the greater value.

The analysis of the impact of an increase in labour efficiency on employment is a little more complex. Setting $\Gamma_{\gamma}^{l} = 0$ in equation (5) gives

$$\sigma(1-s) + s\eta - 1 = 0 \rightarrow \eta = -\frac{(1-s)}{s}\sigma + \frac{1}{s} \qquad (8)$$

Equation (8) shows the sets of parameter values that result in zero change in employment as a result of an increase in labour productivity. This equation is represented by the line CAD in Figure 1. Again, where combinations of η and σ values lie above and to the right of this line, employment will rise; where below and to the left, it will fall. The direct impact of an increase in labour efficiency is to reduce employment as the same labour services can be delivered by fewer workers. However, any subsequent endogenous output and substitution effects are both positive, so that the higher the value of either η or σ, the lower the reduction (or higher the increase) in employment.

Finally the same approach can be taken to the impact of an increase in labour efficiency on total energy use; that is the sum of all energy use in both production and consumption. Again, setting $\Gamma_{\gamma}^{e^T} = 0$ in equation (6) and rearranging gives the set of parameters where total energy use is zero. This is where:

$$\eta = \frac{\omega s - (1-\omega)(1-s)}{s}\sigma + \frac{(1-\omega)}{s} \qquad (9)$$

Equation (9) is shown as FAB in Figure 1. Both the intercept on the η axis and the slope are positive and take values between zero and one.[3] Further, FAB passes through point A. That is to say, it is satisfied by the (σ, η) parameter values (1,1).

If FAB is compared to OAE, we expect a positive intercept on the η axis (where $\sigma = 0$). As argued earlier, at the origin, where $\eta, \sigma = 0$, energy use in production remains constant, but employment falls. This implies that energy in consumption will fall too as household income is reduced. For total energy to remain constant, output must rise, increasing the derived demand for energy in production and also reducing the fall in energy use in consumption. Therefore with a Leontief production function, that is where there are fixed coefficients so that $\sigma = 0$, the elasticity f demand for the product must be positive, so that $\eta > 0$.

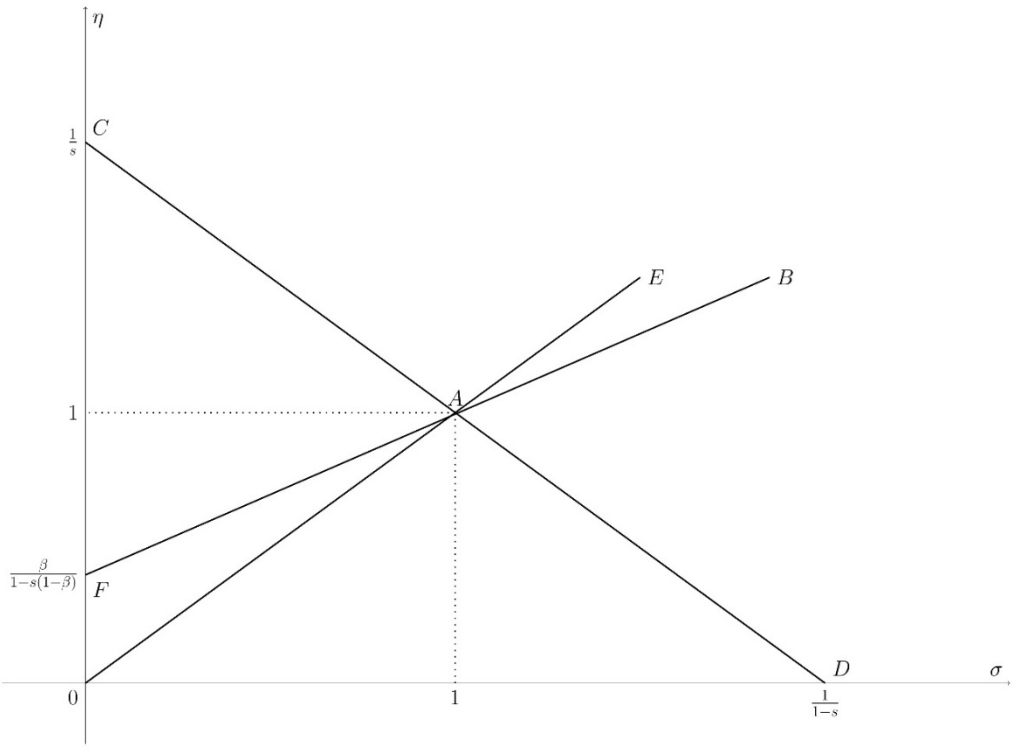
[3] Using expression (2), the intercept is given as: $1 > \frac{1-\omega}{s} = \frac{\beta}{1-(1-\beta)s} > 0$ and the slope is:

$1 > \frac{\omega s - (1-\omega)(1-s)}{s} = \frac{(1-s)(1-\beta)}{1-(1-\beta)s} > 0$.

We note that 0AE, FAB and CAD all pass through the point A, which is where $\eta, \sigma = 1$. With these parameters, the product demand curve has unitary elasticity meaning that total expenditure on the product is independent of the price. With elasticity of substitution equal to one, the production function takes a Cobb-Douglas form where similarly the share of income going to each input is invariant to their price. Under these circumstances, the change in labour efficiency has no impact on either employment or energy use in production. As labour is unchanged, there is also no change in energy use in consumption. Setting $\eta, \sigma = 1$ therefore satisfies equations (4), (5) and (6) and all the zero energy use and employment elasticities pass through A.

Figure 1 identifies six possible outcomes for labour use, energy use in production, and total energy use. These are the six areas delineated by the lines 0AE, CAD and FAB. For an increase in labour productivity to reduce the total energy use requires parameter combinations lying below and to the right of the line FAB. For employment simultaneously to rise, the parameters also need to lie in the area BAD. In this area energy use in production also falls. If a rise in labour use, energy use in production, and total energy use are designated by positive signs, then the six areas are associated with the following outcomes: CAE (+,+,+); EAB (+,-,+); BAD(+,-,-); DA0(-,-,-); FA0(-,+,-); and FAC (-,+,+).[4]

Figure 1: Parameter combinations giving zero energy use and employment elasticities with respect to labour efficiency changes*



* 0AE identifies zero production-energy-use, FAB zero total-energy-use and CAD total-employment elasticities.

[4] Conceivably there are 2^3=8 combinations. However, if employment increases, it is not possible for there to be a fall in total energy use without a fall in energy use in production. This rules out the combination +,+,-. Using a similar logic, the outcome -,-,+ is also not possible.

3.3. Social Welfare Function

Given exogenous values of η and σ, government policy to increase labour productivity is likely to involve trade-offs. One approach is to think of the government as having a Social Welfare Function where proportionate changes in welfare are calculated as the weighted sum of the proportionate changes in its components. In this case, we are particularly concerned with employment gains and total energy reduction so that that changes in welfare, $\dot{W}$, can be defined as[5]:

$$\dot{W} = \kappa \dot{l} - (1-\kappa)\dot{e}^T \quad (8)$$

Again the dot notation represents proportionate changes. The parameters κ and $1-\kappa$ are the weights on employment increases and energy reductions respectively, with $1 \geq \kappa \geq 0$. Differentiating equation (8) with respect to labour productivity produces:

$$\Gamma_\gamma^W = \kappa \Gamma_\gamma^l - (1-\kappa)\Gamma_\gamma^{e^T} \quad (9)$$

Substituting equations (5) and (6) into (9) gives:

$$\Gamma_\gamma^W = s\eta(2\kappa - 1) + \left[2\kappa(1-s) + \omega(1-\kappa) - (1-s)\right]\sigma + \left[(1 - 2\kappa - \omega(1-\kappa)\right] \quad (10)$$

3.3.1 κ= 0.5

It is useful to begin by considering the case where increased employment and reduced energy use are weighted equally, so that $\kappa = 0.5$. In this case, the terms in η drop out; any variation in the value of the elasticity of demand for the product has an equal and opposite impact on the two elements of the Social Welfare Function so that the net effect is zero. In this case, the elasticity of welfare with respect to labour efficiency depends solely on the value of the elasticity of substitution (and the initial share parameters):

$$\Gamma_\gamma^W = 0.5\omega(\sigma - 1) > 0 \quad iff \quad \sigma > 1 \quad (11)$$

Figure 2 is constructed in a similar way to Figure 1. It shows combinations of η and σ where the welfare elasticities are zero, so that an increase in labour efficiency would have a zero impact on social welfare. Where $\kappa = 0.5$, this is a vertical line GAH that cuts the σ axis at G where $\sigma = 1$. Points to the right give a welfare gain, those to the left a welfare loss. Essentially, where output changes have perfectly offsetting proportionate impacts on the employment and energy use terms, the substitution elasticity in production becomes dominant in determining the change in welfare. As σ increases, there is an increasing substitution of labour for energy in production, which increases the welfare elasticity.

3.3.2 κ ≠ 0.5

[5] Recall that in this case changes in employment also represent changes in GDP.

In the case where proportionate employment increases and energy use reductions are weighted unequally, so that $\kappa \neq 0.5$, setting $\Gamma_{\gamma}^{W} = 0$ in equation (10) gives the expression:

$$\eta = a_0 + a_1\sigma \qquad (12)$$

where $a_0 = \frac{\left[(1-2\kappa-\omega(1-\kappa)\right]}{s(1-2\kappa)}$ and $a_1 = \frac{\left[2\kappa(1-s)+\omega(1-\kappa)-(1-s))\right]}{s(1-2\kappa)}$. Equation (12) can be used to identify the combinations of η and σ in Figure 2 which give a zero welfare elasticity with unequal weights on the employment and energy reduction arguments.[6] It is useful to recognise that again these lines all pass through the point where $(\sigma,\eta) = (1,1)$, labelled A, as in Figure 1; with these parameters there is no change in energy use or employment, so weighting is irrelevant. The slope of the zero welfare elasticity line is given by a_1 and the intercepts on the η and σ axes are a_0 and $-a_0/a_1$ respectively.

If $1 \geq \kappa > 0.5$, implying that proportionate employment increases are weighted higher than reductions in energy use, $s(1-2\kappa)$ is negative which means that a_1, and therefore the slope of the zero welfare elasticity line, is also negative. This is represented by the generic line JAK in Figure 2, which cuts the η axis at point J. 0J and 0K are both positive and take values greater than 1.[7] Points to the right of and above the line JAK represent parameter combinations where an increase in labour efficiency will increase social welfare; points to the left and below where social welfare will be reduced. As κ increases from 0.5 to 1, the corresponding JAK lines describes an arc pivoted around point A which go from line GAH where $\kappa = 0.5$ to CAD where $\kappa = 1$.

Where $0.5 > \kappa \geq 0$, $s(1-2\kappa)$ is positive. This implies that the slope of the corresponding generic zero welfare elasticity line in Figure 2, LAM, is positive. With parameter combinations to the right of this line, an increase in labour productivity will give a positive change in welfare; combinations to the left produce a reduction in welfare. Again, in this case the range of zero elasticity lines goes from GAH, where $\kappa = 0.5$, to FAB when $\kappa = 0$.[8]

3.4. Model limitations

The stripped-down model developed in this section focuses on a small range of key relationships; those that are likely to play an important part in determining the response of the economy and the energy system to improvements in labour efficiency. However, this focus has been achieved through extreme simplification and the suppression of effects which could have a significant impact on the result. We therefore extend the analysis using simulation from a CGE model.

The CGE model, UK-ENVI, employed in this paper contains a strong theoretical base, essentially consistent with the approach adopted in this section. However, it allows a wider range of economic activity and greater degree of disaggregation. For example, investment and government expenditure

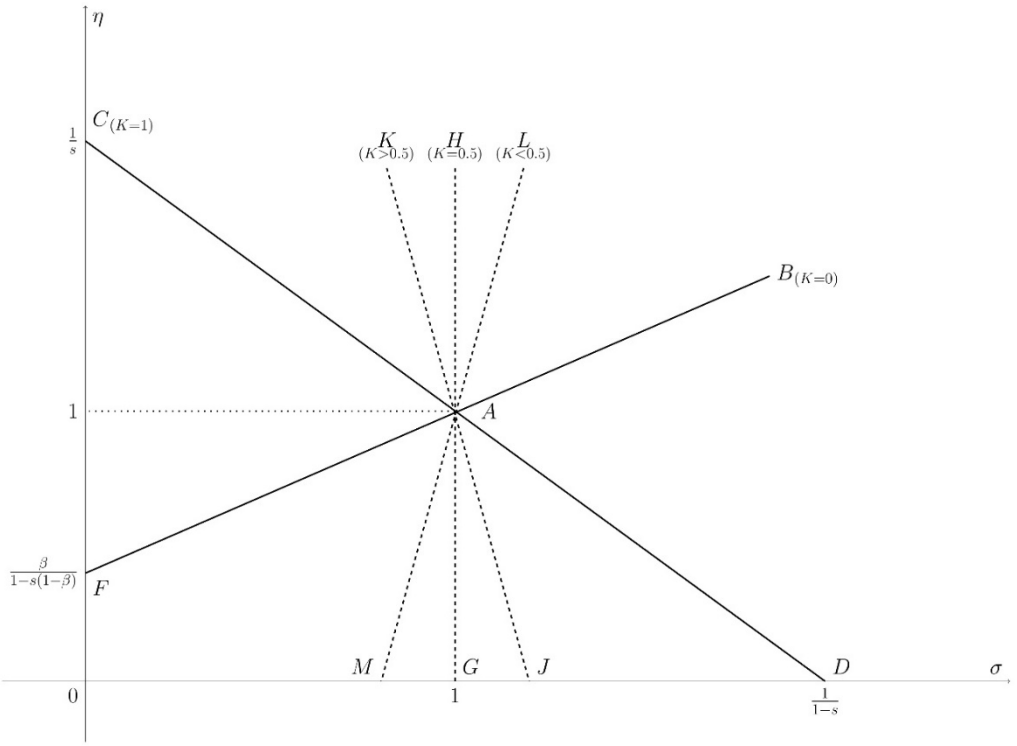
[6] We separately deal with the cases where $\kappa = 0.5$ and $\kappa \neq 0.5$ because in equation (12), a_0 and a_1 are not determined where $\kappa = 0.5$.

[7] These intercept results are shown in Appendix 2.

[8] The intercept on the η axis is positive for values of $\kappa < \frac{1-\omega}{2-\omega}$.

are now incorporated as elements of final demand for domestic output additional to exports. A wider range of productive inputs is incorporated, including capital and intermediate inputs, and additionally economic activity is further disaggregated by sector. Moreover, the prices of inputs are typically endogenous, determined not only by the exogenous supply-side shocks, such as changes in efficiency, but also by subsequent market adjustments. A particular example would be the price of labour, which is likely to be sensitive to changes in the level of employment and also a key source of household income. Finally, the model used here is parameterised on a set of accounts for the UK economy, so that the relative size of share parameters and endogenous economic impacts are appropriately calibrated. The details of this model are outlined in the next section.

Figure 2: Parameter combinations giving zero social welfare elasticities with respect to labour efficiency for selected values of the weight on employment increases



4. Model and data

We simulate the economic and energy system-wide impacts of illustrative improvements in labour productivity using a computable general equilibrium (CGE) model of the UK, UK-ENVI, purpose-built to capture the interdependence of the energy and non-energy sub-systems. Versions of this model have been employed previously to analyse the impacts of increased energy efficiency in industrial and household use (Allan et al., 2007; Figus et al., 2017; and Lecca et al., 2014). We adopt here the forward-looking variant of the model, in 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.[9]

4.1. Consumption and trade

Consumption is modelled to reflect the behaviour of a representative household that maximises its discounted intertemporal utility, subject to a lifetime wealth constraint. In each time period *t* we model the aggregate consumption decision of each of the five representative households *h* as follows

$$C_{h,t} = YNG_{h,t} - SAV_{h,t} - HTAX_{h,t} - CTAX_{h,t} \tag{13}$$

where total consumption, *C,* is a function of income, *YNG*, savings, *SAV*, income taxes, *HTAX*, and taxes on consumption, *CTAX*. 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 use, consumption is allocated within each period between "residential energy", *EC*, and "transport and non-energy", *TNEC,* sectors as indicated in the top level of the consumption structure shown in Figure 3. This choice is made in accordance with the following constant elasticity of substitution (CES) function:

$$C_{h,t} = \left[\delta_h^E \left(\gamma EC_{h,t} \right)^{\frac{\varepsilon_h - 1}{\varepsilon_h}} + \left(1 - \delta_h^E \right) TNEC_{h,t}^{\frac{\varepsilon_h - 1}{\varepsilon_h}} \right]^{\frac{\varepsilon_h}{\varepsilon_h - 1}} \tag{14}$$

where ε is the elasticity of substitution in consumption, δ ϵ (0,1) is the share parameter and γ the efficiency parameter of energy in consumption. In the absence of better information, in all households we impose a value of 0.61 for ε; this 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 3, although coal consumed by households represents less than 0.01% of total energy consumption. In both equations (13) and (14) the h subscript reflects the fact that household results are available disaggregated by income quintiles.

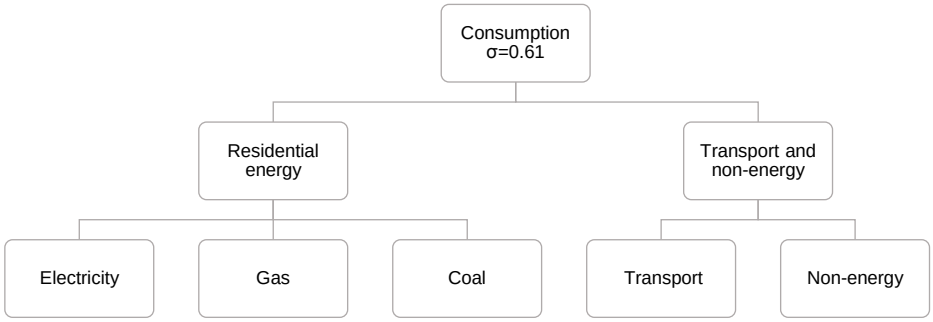
Moreover, we assume that the individual can consume goods produced both domestically and imported, where imports are combined with domestic goods under the Armington assumption of imperfect substitution (Armington, 1969), so that:

$$QH_{i,t} = \gamma_i^f \cdot \left[\delta_i^{hir} \cdot QHIR_{i,t}^{\rho_i^A} + \delta_i^{hm} \cdot QHM_{i,t}^{\rho_i^A} \right]^{\frac{1}{\rho_i^A}} \tag{15}$$

where *QH* is total household consumption by sector, *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 in national prices.

Figure 3: The structure of consumption

[9] A full mathematical description of the model is given in Ross et al. (2018).

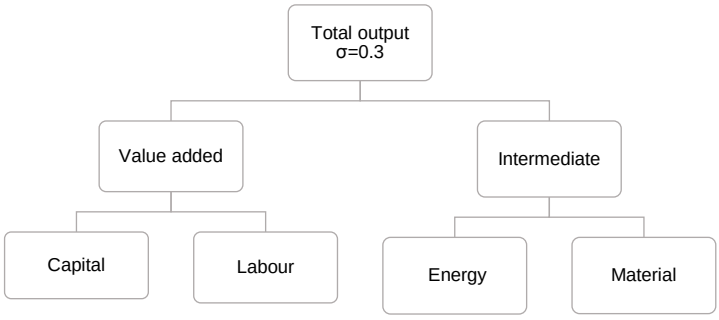


It must be noted that the Armington assumption applies to the decisions of both producers and consumers. Following from equation (15), consumers choose over imported and domestic goods depending on relative prices and the Armington elasticity. For firms, intermediate purchases in each industry are modelled as the demand for a composite commodity with fixed (Leontief) coefficients (as outlined in the following section in more detail). These are substitutable for imported commodities via an Armington link, which is sensitive to relative prices.

4.2. Production, productivity and investment

In each of the thirty industry sectors, the production structure is characterised by a capital, labour, energy and materials (KLEM) nested CES production function. As we show in Figure 4, the combination of labour and capital forms value added, while energy and materials make up intermediate inputs. In turn, the combination of intermediates and value added comprise total output in each sector.

Figure 4: The structure of production



The value-added production function for each activity, i, related to the left hand branch of the production hierarchy, is given as:

$$VA_{i,t} = \left[a_i (\gamma L_{i,t})^{\frac{\varepsilon_i - 1}{\varepsilon_i}} + (1-\alpha_i)(K_{i,t})^{\frac{\varepsilon_i - 1}{\varepsilon_i}} \right]^{-\frac{\varepsilon_i - 1}{\varepsilon_i}} \quad (16)$$

where L and K are labour and capital inputs, γ is the labour productivity parameter, initially set to one, and ε is the elasticity of substitution between capital and labour (set to 0.3). An increases in the labour efficiency (Harrod-neutral technical change) is introduced by changing the labour-augmenting efficiency parameter γ.

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:

$$Max V_t \sum_{t=0}^{\infty} \left(\frac{1}{1+r} \right)^t \left[\pi_t - I_t \left(1 + g\left(x_t \right) \right) \right] \quad \text{subject to } \dot{K}_t = I_t - \delta K_t \tag{17}$$

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.

4.3. The labour market

Model outcomes are sensitive to the operation of the labour market. We consider three alternative labour market closures here. Our benchmark (or reference) case for these simulations, the fixed real wage (FRW) closure, holds the real wage constant at its base-year level so that:

$$\frac{w_t}{cpi_t} = \frac{w_0}{cpi_0} \tag{18}$$

where w_t and cpi_t are, respectively, the post-tax wage and consumer price index in time period t. This case effectively implies an infinitely elastic supply of labour at the base-period real wage. It is a useful benchmark and also represents the outcome where there is costless migration so that workers can move freely between economies in response to variations in the real wage. However, the fixed real wage is not our preferred closure.

Our preferred labour market closure embodies a wage curve (Blanchflower & Oswald, 2005). This approach is supported by extensive empirical evidence, at both the national and regional level, for an inverse relation between the rate of unemployment and the real wage. It implies that wages are determined in an imperfectly competitive context, according to the following bargained real wage (BRW) specification:

$$\ln\left[\frac{w_t}{cpi_t} \right] = \rho - \phi \ln(u_t) \tag{19}$$

Where ϕ is the elasticity of the real wage with respect to the level of unemployment, u_t , and ρ is a parameter calibrated to the initial equilibrium steady state. In the simulations reported in Section 6, the working population is assumed to be fixed and this model implies the presence of involuntary unemployment, with BRW lying above the competitive supply curve for labour.

Finally, conventional national CGE models often make the simplifying assumption of an entirely exogenous labour supply, Ls , with both population and the participation rate fixed. In such a closure, labour supply exhibits a zero elasticity with respect to the real wage. This exogenous labour supply (ELS) characterisation of the labour market implies that employment is fixed at the base-year level.

$$Ls_t = Ls_0 \tag{20}$$

This characterisation of the labour market would imply that the UK operates under a very tight labour market constraint. In the short run, capital is fixed in each sector, so that under this closure aggregate GDP can only vary through reallocation of labour across sectors. Even in the long-run, employment is effectively fixed and is invariant to any change in demand. However, capital stocks can adjust in both in terms of their aggregate level and their distribution across sectors in response to changes in capital rental rates.[10]

The exogenous labour supply and the fixed real wage closures 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 bargained real wage closure represents an intermediate case in which the effective (bargaining-determined) level of employment varies positively with the real consumption wage. [11]

4.4. Government

In the simulations reported in Section 6, government expenditure, GEXPT, is held constant in real terms. Government income in time period t, GY_t , 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* , taxed at the rate τ , and foreign remittance FE, which are taken to be exogenous.[12] Therefore:

$$GY_t = d_g KY_t + IBT_t + \overline{\tau}_t \cdot LY_t + FE_0 \tag{21}$$

The Government budget *surplus, GOVBAL,* is then equal to the difference between government income and government spending so that:

$$GOVBAL_T = GY_T - \overline{GEXP_T} \tag{22}$$

4.5. Dataset: income disaggregation and energy use

Calibration follows a common procedure for dynamic CGE models which is to assume that the economy is initially in steady state equilibrium (Adams & Higgs, 1990). The data base employed is the UK Social

[10] For simplicity we abstract from labour supply changes that occur through natural population growth or migration, although the fixed real wage model emulates many of the features of a system with endogenous (flow) migration.

[11] While these cases provide a useful range of UK labour market options, there may be some evidence of a degree of nominal wage inflexibility. The implications of this can be explored using the limiting case of a fixed nominal wage.

[12] Note that the income tax is levied at a fixed rate τ which is calibrated to the base-year data set.

Accounting Matrix (SAM) for 2010 (the latest data available at the time of writing).[13] The UK-ENVI model has 30 separate production sectors, including the main energy supply industries that encompass the supply of coal, refined oil, gas and electricity. These are detailed in Appendix 3. 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 elasticities and constant terms. Such parameters are either exogenously imposed, based on econometric estimation where available, or determined through the calibration process. Base year industrial territorial CO_2 emissions are calculated, and linked to the CGE sectoral primary fuel use according to Allan et al., (2018).

5. Simulation strategy

The main aim of the present paper is to quantify, through simulation, the impacts of a successful economic growth policy on key elements of the economic and energy systems; specifically, the effects of increasing labour productivity in line with the UK's Industrial Strategy (UK Government, 2017b). We adopt a rather broad brush interpretation of the productivity-enhancing aspects of such a strategy. An exogenous (and costless) permanent 1.5% step increase in labour productivity is introduced across all production sectors.[14] This value is broadly in line with the difference between the present UK and average EU28 labour productivity levels (OECD, 2017).

Given that the model is calibrated to be initially in long-run equilibrium, when it 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, unless otherwise specified, are typically expressed as percentage changes in the endogenous variables relative to this unchanging equilibrium. All of the effects reported are therefore directly attributable to the exogenous shocks to labour productivity. Given that the CGE model uses annual data, we take each period in the adjustment process to be one year.

To observe the evolution of key economic and energy-use variables over time, simulations are run for 50 periods (years). While we report selected period-by-period results, the focus is primarily on figures for two conceptual time periods. The first is the short run, which is the period immediately after the introduction of the exogenous shock. In this time period, the capital stock is fixed in each sector but labour is perfectly flexible across sectors. In the long run, capital stocks fully adjust both in aggregate and across all sectors to the shock and are again equal to their desired levels.

Simulations are run with all three of the labour market closures. Sensitivity analysis is also performed around variations in key parameter values.

[13] Emonts-Holley et al. (2014) give a detailed description of the methods employed to construct these data. The SAM is available for download at: https://doi.org/10.15129/bf6809d0-4849-4fd7-a283-916b5e765950

[14] It is a simplification to represent the direct impact of such a strategy as generating a step increase in efficiency. However, whilst a more gradual introduction will affect the time-path of adjustment it does not affect the long-run equilibrium. Ross (2017) explores this in detail.

6. Simulation results

The simulation results reflect the basic analysis outlined in Section 3, but incorporate additional economic interaction suppressed in the earlier theory. We take as a benchmark the long-run results generated under the fixed real wage variant of the model. These results are presented in the first column of Table 1. These figures report the outcome where the economy has fully adjusted to the efficiency disturbance and the fixed-real-wage labour-market closure is chosen in order to minimize the endogenous variation in relative prices.

6.1. Benchmark simulation: full adjustment with a fixed real wage

As we expect, the 1.5% improvement in labour productivity increases GDP, in this case by 1.96%. In terms of the analysis in Section 3, the economy lies within the area CAE in Figure 1: employment, energy use in production and total energy use increase by 0.52%, 1.66% and 1.40% respectively. We compare the characteristics of the CGE framework with the analytical model given in Section 3 and reflect on some of these differences in these benchmark results.

A key difference relates to the sources of demand for domestic production. The analysis in Section 3 employs an extreme export base model. In the CGE simulations reported in Table 1, domestic output also meets demand for intermediate inputs, household consumption, investment and publicly-supplied goods and services. This has two important implications. First, the reduction in product prices that accompanies the increased labour efficiency will lead to the substitution of domestic production for imports in these uses. The stimulus that this generates in the demand for domestic output will depend on the weighted sum of the elasticities in these uses, together with the demand for exports. This would be the value that broadly corresponds to η in the previous analysis.

The second issue is that the reduction in the price of any one commodity depends not only on the increase in the productivity of the labour directly used in its production, but also the labour indirectly employed in its intermediate inputs and, in the long run, capital goods. In the present case of a fixed real wage, it will also incorporate efficiency improvements in the embedded labour in the domestically produced goods that household consume. This implies that the share of labour in output, that is the value of s in the earlier analysis, is much greater than the share of direct labour in total output. This is reflected in the size of the price reductions that accompany the labour productivity shock. For the closures where the labour market determines the real wage, that the fixed and bargained real wage cases, for some sectors, the reduction in price is actually greater than the 1.5% increase in labour productivity.[15]

A linked consideration is that in the CGE model, energy is not only imported but also domestically produced, which implies that its price is sensitive to the improvement in labour efficiency. In this simulation, energy prices fall by 0.89% which will affect the degree of substitution between energy and other inputs in production and consumption. We therefore find changes in the use of energy which

[15] The price of a commodity can fall by more than the increase in labour productivity because where the real wage is held constant, the nominal wage falls as the CPI falls. This implies that the price of the labour input falls by more than the increase in labour productivity resulting in price reductions in some labour intensive products that are greater than the 1.5% increase in labour productivity.

differ to some extent to those considered in the analytical model. For instance, exports of energy increase by 1.55% as the price falls. Further, energy in consumption fails to rise as rapidly as total household consumption, 0.24% as against 0.53%, as the reduction in the energy price is less than the 1.32% fall in the CPI, so that energy becomes relatively more expensive.

The analytical model has a very simple production structure. Not only does it ignore intermediates but it also fails to incorporate capital as a separate factor of production. In long-run equilibrium, as in the benchmark simulation, the price of each commodity covers the cost of all inputs. This includes a cost for capital which comprises the replacement investment for capital depreciation plus interest on the capital stock. The 1.86% increase in investment in our benchmark case therefore also equals the proportionate increase in the capital stock. The 1.96% rise in GDP is therefore the weighted sum of the 2.02% (1.5% + 0.52%) increase in labour inputs, measured in efficiency units, and the 1.86% rise in capital inputs. The productivity increase clearly hits long-run economic goals. As far as environmental targets are concerned, the situation is less sanguine. There is an increase in CO_2 of 1.88%. However, the ratio of both energy use and CO_2 to GDP falls, by 0.55% and 0.08% respectively, though they rise per worker.

We identify here the incremental change in emissions that is likely to arise from the improvement in labour productivity alone. This identifies the additional challenge made to meeting the Government's emission targets that is solely attributable to the increase in labour productivity. Of course, in practice, energy policies directed at decarbonisation are in place, and it is instructive to consider how these might be adjusted to counter any adverse effects on emissions generated by the increase in productivity. An idea of the scale of the change required is to consider by how much the emissions in the electricity producing sector would need to fall so as to offset entirely the emissions directly attributable to the increase in productivity. A fall of 5.4% in emissions in the electricity production sector would offset the 1.88% increase in emissions arising from the 1.5% increase in labour productivity. Given that emissions in the electricity production sector have fallen by nearly 50% in the UK over the last seven years it is feasible that these emissions could be offset. This said, other things being equal some adjustment in energy policy at the margin would be required to offset the additional emissions associated with an expansion in exports.

6.2. Short-term benchmark result

A key characteristic of the capital stock is that it is generally immobile in any given time period and can only gradually adjust to a new equilibrium. This is illustrated in the results reported in column 4 of Table 1 which show the short-run (period-1) results for the fixed real wage simulation. In this case, the0.53% increase in GDP is less than one third of the long-run expansion. An employment reduction of 0.63% also accompanies this expansion with energy use increasing by 0.27%.[16]

The limited ability of the economy to expand in the short run means that the increase in the derived demand for labour, as measured in efficiency units, is not enough to offset the direct increase in labour productivity. For energy use, again there are countervailing forces. First, energy prices only fall by

[16] In the short run, the 0.53% increase in GDP can again be seen as the weighted sum of the zero change in capital and 0.87% (1.5%-0.63%) change in labour inputs, measured in efficiency units.

0.20%, less than the general fall in domestic output and the CPI, which declines by 0.45%. Therefore in intermediate inputs and household consumption there will be some substitution against energy. Therefore although GDP increases by 0.53%, energy use in production only rises by 0.27%.[17] However, because employment falls, total household consumption also falls, by 0.20% and household consumption of energy by 0.36%. However, energy exports and especially demand from increased investment rise, by 0.17% and 0.92% respectively. This sums to the total increase in energy use of 0.27%.

Figure 5 details the time path adjustments for GDP, employment, and total energy use broken down into production and consumption use. All variables take a significant period of time to fully adjust, though all are close to their long-run equilibrium values by period 20. The impact on GDP is unambiguously positive throughout all simulation periods and the expansion is relatively rapid. The increase in GDP reaches around one half of its long-run value by period 4. The impact on employment, however, is initially negative, so that unemployment initially increases. Although employment subsequently improves, it does not reach its base-period level until period 7 and takes to period 12 to be at half its long-run increase.

The lines that track the evolution of the three energy-use measures lie between the GDP and employment functions. Energy use in production is consistently positive and lies slightly below the GDP function. On the other hand, the change in energy use in consumption is initially negative, and although positive from period 3 broadly lies just above the employment function. Total energy use is the weighted sum of the two. In absolute terms, energy use in production constitutes around 60% of total energy use. The 0.29% rise in energy use in production in the short run therefore increases total energy use despite the 0.11% fall in household energy consumption. The change in total energy use is always positive and reaches one half of its long-run increase by period 4.

6.3. Different labour market closures

The bench-mark fixed real wage (FRW) model holds the real wage constant. However, as outlined in Section 4, there are alternative labour-market specifications and the choice of labour market closure will affect the policy effectiveness of the efficiency improvement. These labour market alternatives are illustrated in Figure 6. This figure represents the conceptual relationship between the alternative labour-market closures under different time-periods but is constructed using the actual outcomes from the alternative simulations reported in Table 1. This illustrates, in this respect, the congruence between the CGE simulation results and the underlying economic theory.

In Figure 6 the horizontal and vertical axes represent percentage changes in employment and the real wage, both measured in natural units. That is to say, we are identifying changes in the number of workers employed and the real wage per worker. The economy is initially located at the origin and movements along the axes represent movements away from that initial equilibrium. Imagine the short- and long-run downward sloping labour demand curves initially passing through the origin, where the short-run curve is less elastic (steeper) than the long-run curve. These relative elasticities represent the phenomena identified in Section 6.2. This is that in the short run the economy is restricted by capital

[17] There might be compositional effects here too, dependent upon which sectors expand the most as a result of the efficiency improvements, and their energy intensity.

fixity and is therefore less responsive to changes in relative prices over this time period. In Figure 6, consistent with model outcomes, the short-run and long-run labour demand curves are inelastic and elastic respectively. That is to say, the short-run elasticity of labour demand with respect to the real wage is less than one, the long-run greater than one.

The increase in labour productivity moves each curve upwards and to the left. These shifts can be anchored by considering the outcome were the real wage simultaneously to increase by the full amount (1.5%) of the increase in labour productivity.[18] This implies that the price of labour in efficiency units is unchanged: each worker costs 1.5% more but their productivity is 1.5% higher. This therefore implies that the firms' costs are also unaffected, so that prices, outputs and incomes are remain constant. However, firms now require 1.5% less workers; employment measured in natural units therefore falls by 1.5%. This means that the short- and long-run labor demand curves now pass through the point (-1.5%, 1.5%) in Figure 6 at point A.

From Table 1, where there is a fixed real wage (FRW), the employment falls in the short run by 0.63% and increases in the long run by 0.53%. This is means that these new short- and long-run labour demand curves cut the x–axis (where there is zero change in the real wage) at the points (0,-0.63) and (0, 0.53) respectively. These are indicated by points B and C in Figure 6.

However, our preferred model is one that incorporates a bargained real wage (BRW) as given by equation (19). This can be reformulated as a positive relationship between a change in the employment rate and a corresponding change in the real wage.[19] This is shown in Figure 6 as the line D0F through the origin. This implies that with the bargained real wage closure, the short-run fall in employment is accompanied by a reduction in the real wage. Equilibrium is achieved where the short-run labour demand curve cuts the bargained real wage function at point D, which has co-ordinates (-0.38%, -0.40%); real wage is lower, but employment higher than at B. Similarly, in the long-run, the expansion of employment that occurs with a fixed real wage leads to the wage being bargained up until the long-run labour demand curve cuts the bargained real wage function at F, with co-ordinates (0.21%, 0.23%). The simulation results for the whole range of endogenous variables under the bargained real wage are shown in columns 2 and 5 in Table 1.

It is clear from the results in Table 1 that the introduction of the bargained real wage cushions the impact of the efficiency shock. In the long-run simulation, the improvement in competitiveness is lower and the increases in GDP, employment and energy use, at 1.66%, 0.21% and 1.18%, are all less than with the fixed real wage. Although the real wage increases by 0.23%, because the long-run labour demand is elastic, total household consumption increases by less than under the fixed real wage. This means that although all forms of energy use and total emissions increase with the introduction of the improved labour efficiency, these are lower than under the fixed real wage closure. However, the reductions in energy and emissions intensities are also lower with the bargained real wage.

For the short-run results, the cushioning effect of a degree of wage flexibility operates in the opposite direction for those variables tracking aggregate economic activity. The reduction in prices is greater as the real wage falls, so that competitiveness and GDP increase by more, whilst employment declines by less, than in the fixed real wage case. For GDP, employment, energy use and CO_2 emissions, the short-

[18] This would be the outcome under pure productivity bargaining.

[19] Equation (19) expresses a negative relationship between the real wage and the unemployment rate. However, given that the employment rate is 1 minus the unemployment rate, this relationship can be reformulated as shown in Figure 6.

run changes are 0.68%, -0.38%, 0.40% and 0.34% respectively. In this case, under the bargaining closure the short-run reductions in energy and emissions intensity are greater than with the fixed real wage.

Some CGE models close the labour market by holding an exogenous labour supply fixed (ELS), in natural units. This is associated with points G and H in Figure 6. In these cases, flexibility in the wage is required so as to clear the labour market at the original employment level. In the case of the short run, this means an even greater (1.03%) reduction in the real wage, so that point G is (0,-1.03%). Again, in the long run the opposite applies. The real wage must rise even further, by 0.38%, in order to choke off the increased demand for labour. Point H is therefore (0, 0.38%).

With ELS, the long run increase in the wage reduces further the competitive stimulus supplied by the efficiency improvement. However, there is still a 1.45% increase in GDP. This is made up of the weighted sum of the 1.5% increase in labour inputs, measured in efficiency units, and the 1.38% increase in the capital stock. In the long-run simulation, the impacts of increased real wages identified for the bargained real wage, are further extended in this closure. However, note that all prices still fall and that economic activity and energy use still increase. In the short run again wage flexibility now stimulates competitiveness and not only aggregate output but also energy use, as compared to the other closures.

The system-wide impacts of the increase in labour productivity on economic activity seem unambiguously positive both in the short and the long run. This is reassuring for policy goals set out in the Industrial Strategy; GDP, investment and household incomes increase (we consider more detailed distributional impacts in Section 7.3). There is also a reduction in the trade- and the public-sector deficits. Moreover, these benefits apply across all of the labour market closures that we cover. However, for employment there is the negative direct effect of the increase in efficiency and employment falls in the short run. Over the longer run, however, the demand for labour is stimulated and so employment rises in the closures which embody a degree of flexibility in labour market participation. As such, we see some potential tensions of policy objectives around the level of employment in the short and long runs.

Our analysis highlights the potential positive economic outcomes that can be gained from increasing labour productivity. However, these are accompanied by significant negative environmental effects. In the long run, all forms of energy use and CO_2 emissions increase in response to the increase in labour productivity across all the labour market closures reported here. Total energy use and emissions, however, increase by less than GDP, so that energy and emissions intensities, defined here as energy use and emissions per unit of GDP, fall. As noted previously in more detail, in practice, energy policies directed at decarbonisation are in place. However, other things being equal, some adjustment in energy policy at the margin would be required to offset the additional emissions associated with an increase in labour productivity. We have sought here to isolate the impact of the increase in labour productivity on the energy system, so that an assessment can be made of the extent to which they act to worsen or alleviate trade-offs between economic and environmental objectives at the margin. In terms of a Social Welfare function, if proportionate increases in GDP and reductions in emissions are weighted equally, then increasing labour productivity increases Social Welfare. However, what is clear is that with our default parameter values, such a policy fails to produce an economic-environment win-win.

Table 1: Short and Long-run effects of a 1.5% increase in labour productivity. In % changes from base year.

	Long-run			Short-run		
	FRW	BRW	ELS	FRW	BRW	ELS
GDP	1.96	1.66	1.45	0.53	0.68	0.91
CPI	-1.32	-1.12	-0.98	-0.45	-0.50	-0.60
Unemployment rate (pp difference)	-0.49	-0.20	-	0.59	0.36	-
Total employment	0.52	0.21	-	-0.63	-0.38	-
Nominal wage	-1.32	-0.89	-0.60	-0.45	-0.89	-1.63
Real wage	-	0.23	0.38	-	-0.40	-1.03
Households wealth	0.53	0.45	0.39	-0.17	-0.19	-0.25
Households consumption	0.53	0.45	0.39	-0.20	-0.07	0.08
Labour income	-0.81	-0.69	-0.60	-1.07	-1.27	-1.63
Capital income	0.60	0.51	0.44	1.06	1.47	2.07
Government budget	-8.08	-6.83	-6.00	-2.20	-2.69	-3.50
Investment	1.86	1.57	1.38	1.61	1.97	2.45
Total imports	-1.14	-0.97	-0.85	-0.39	-0.32	-0.30
Total exports	2.38	2.01	1.76	0.70	0.78	0.96
Total energy use (intermediate+final)	1.40	1.18	1.03	0.27	0.40	0.59
- Electricity	1.35	1.14	0.99	0.34	0.52	0.75
- Gas	1.10	0.93	0.81	0.06	0.17	0.32
Energy use in production (total intermediate)	1.66	1.40	1.22	0.29	0.40	0.57
Energy consumption (total final demand)	0.81	0.68	0.59	-0.11	-0.05	0.02
- Households	0.24	0.20	0.17	-0.36	-0.25	-0.15
- Investment	1.77	1.49	1.31	0.92	1.25	1.69
- Exports	1.55	1.31	1.15	0.17	0.17	0.18
Energy output prices	-0.89	-0.75	-0.66	-0.20	-0.22	-0.26
Energy output	1.70	1.44	1.26	0.18	0.27	0.40
Non energy output	1.76	1.48	1.30	0.48	0.63	0.85
Energy intensity (Total energy use/GDP)	-0.55	-0.47	-0.41	-0.26	-0.27	-0.32
Territorial CO_2 emissions	1.88	1.59	1.39	0.24	0.34	0.50
Emission intensity (territorial CO_2/GDP)	-0.08	-0.07	-0.06	-0.28	-0.33	-0.41

Figure 5: Aggregate transition path for GDP, employment, and energy use/consumption of a 1.5% increase in labour productivity, FRW closure. In % changes from base year.

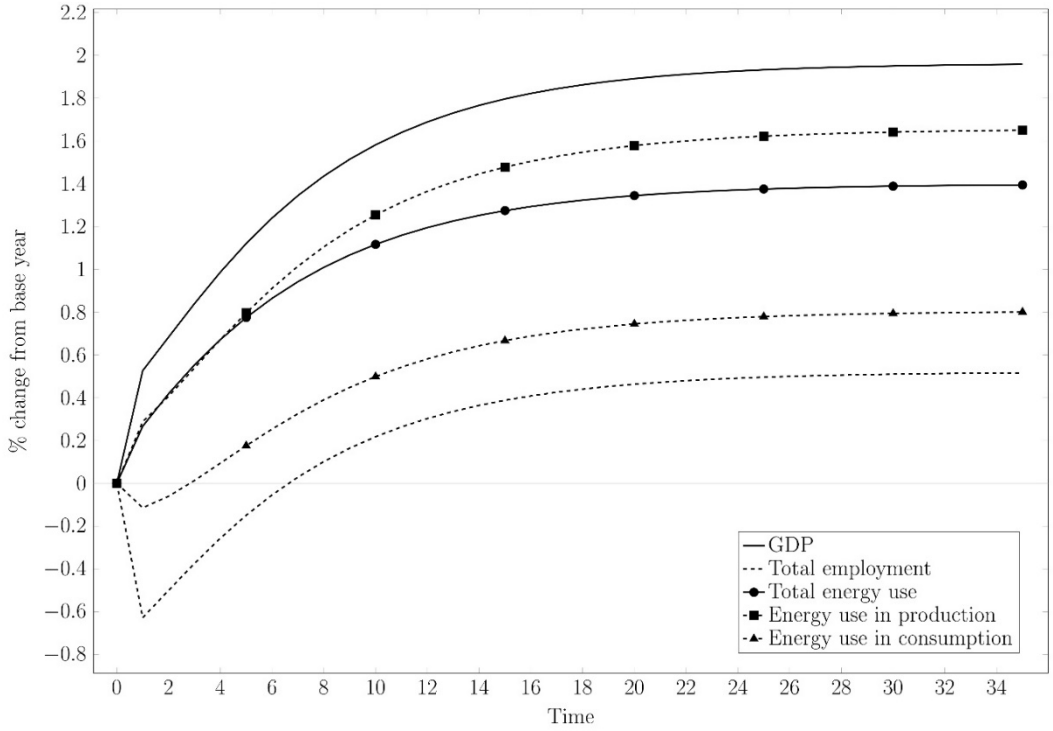
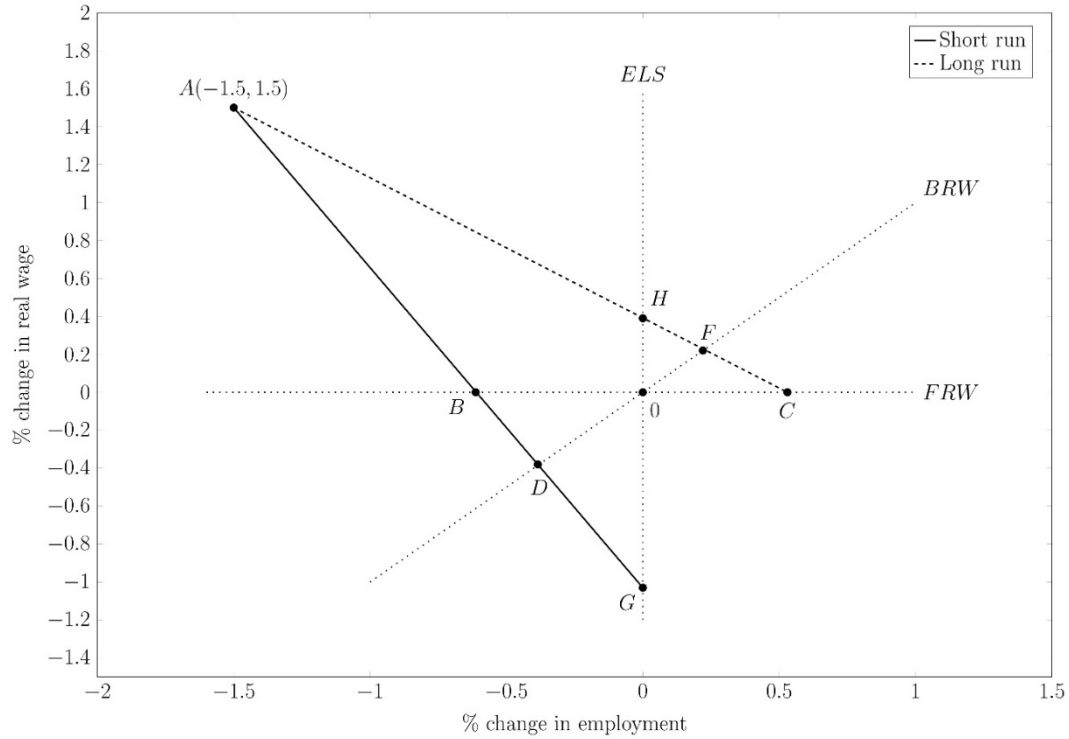


Figure 6: Short- and long-run labour market impacts of a 1.5% increase in labour productivity. In % changes from base year.



7. Sensitivity and disaggregation

It is useful to extend the analysis in two key directions. The first is to test how sensitive the simulation results are to changing key parameters. This is done in Section 7.1. The second is to break down the aggregate results to identify the impact on individual industrial production sectors and household types. These results are shown in Sections 7.2 and 7.3.

7.1. Sensitivity analysis

In Section 3 we use a stylized model to illustrate the potential links between key elasticities and the employment and energy use impacts of an increase in labour productivity. This analysis suggests that these outcomes should be sensitive to varying the elasticity of substitution in production and consumption. In this subsection we present the long-run results for our usual set of economic, energy and environment variables. We again impose a 1.5% increase in labour productivity using our benchmark labour market closure where the real wage is held constant. The results are shown in Table 2.

In this table, for each simulation the Armington trade elasticities are set to unity. All the other production and consumption elasticities, for example those used in equations (14) and (15) in Section 4, are set to the same value. We identify these elasticities in Table 2 as σ , and they range from 0.3 to 3.5. That is to say, we are reporting the variation in the impact of the efficiency improvement as inputs in production and commodities in consumption become more perfect substitutes for one another. We expect from the analysis in Section 3 that as the elasticities increase, there should be substitution of labour for energy in production so that positive outcomes for both energy and economic policy goals are possible.

Note first that GDP is relatively insensitive to changes in elasticities. As σ increases from 0.3 to 3.5, GDP increases only move from 1.00% to 1.07%. However, there is a large variation, involving not just the scale but also the sign, in the employment change figures. At the lowest elasticity level, 0.3, employment falls by 0.37% in response to the labour productivity shock. Where $\sigma = 1$, employment shows a very small increase but for values of σ =2 and 3.5, employment growth is 0.56% and 1.31% respectively. These results are close to what would have been expected from the analysis in Section 3 which shows no change in employment where the demand and substitution elasticities equal one. However, recall that UK-ENVI is much more complex than the extremely stylised analytical model of Section 3.

In the simulation results reported in Table 2, the sensitivity of energy use to changes in the substitution elasticities is much less than the analytical model of Section 3 would suggest. Although the increase in both total energy use and energy use in production falls as the elasticity of substitution increases, even at very high values of σ both of these are positive, though the increase in total energy use when elasticities are 3.5 is very small. A central issue here seems to be the insensitivity of the demand for all intermediate inputs. Whilst this variable increases 0.78% where σ =0.3 it only falls slightly to 0.69% for σ =3.5. Whilst energy makes up a smaller share of total intermediate demand as the substitution elasticity increases, it is never the case that energy use in production falls as a result of the labour productivity increase in the range of elasticities used here.

It is important to note the insensitivity of energy use to variations in the substitution elasticities reinforces the notion that UK policy on climate change must be at least conscious of the implications of a more successful industrial policy. However, investigation of the factors which are behind the relative constancy of the energy use results should have high priority.

Table 2: Sensitivity analysis, long-run effects of a 1.5% increase in labour productivity. In % changes from base year.

	Armington (n=1.0)							
	σ=0.3	σ=0.7	σ=1	σ=1.3	σ=2	σ=2.5	σ=3	σ=3.5
GDP	1.00	1.02	1.04	1.05	1.06	1.07	1.07	1.07
CPI	-1.31	-1.36	-1.39	-1.43	-1.49	-1.54	-1.58	-1.61
Unemployment rate (pp difference)	0.34	0.13	-0.03	-0.18	-0.53	-0.76	-1.00	-1.23
Total employment	-0.37	-0.14	0.03	0.19	0.56	0.81	1.06	1.31
Nominal wage	-1.31	-1.36	-1.39	-1.43	-1.49	-1.54	-1.58	-1.61
Real wage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Households wealth	-0.10	-0.01	0.06	0.12	0.26	0.35	0.44	0.53
Households consumption	-0.14	-0.08	-0.04	-0.01	0.07	0.13	0.18	0.23
Labour income	-1.67	-1.50	-1.37	-1.24	-0.94	-0.74	-0.53	-0.33
Capital income	-0.44	-0.80	-1.07	-1.33	-1.95	-2.38	-2.82	-3.25
Government budget	-4.84	-5.41	-5.82	-6.23	-7.13	-7.76	-8.37	-8.98
Investment	0.80	0.49	0.26	0.03	-0.52	-0.91	-1.31	-1.70
Total imports	-1.13	-1.22	-1.28	-1.33	-1.45	-1.54	-1.62	-1.69
Total exports	1.17	1.23	1.27	1.31	1.38	1.43	1.48	1.52
Total intermediates (regional + imports)	0.78	0.77	0.77	0.76	0.74	0.73	0.71	0.69
Total energy use (intermediate+final)	0.46	0.36	0.28	0.23	0.14	0.09	0.05	0.02
- Electricity	0.39	0.28	0.20	0.14	0.03	-0.03	-0.09	-0.14
- Gas	0.20	0.16	0.12	0.10	0.13	0.18	0.25	0.34
Energy use in production (total intermediate)	0.61	0.46	0.37	0.31	0.21	0.17	0.14	0.11
Energy consumption (total final demand)	0.09	0.14	0.14	0.15	0.20	0.23	0.28	0.32
- Households	-0.42	-0.39	-0.42	-0.43	-0.42	-0.39	-0.34	-0.30
- Investment	0.71	0.45	0.25	0.06	-0.34	-0.62	-0.90	-1.17
- Exports	0.76	0.85	0.91	0.96	1.06	1.12	1.18	1.23
Energy output prices	-0.88	-1.00	-1.08	-1.14	-1.27	-1.34	-1.41	-1.46
Energy output	0.63	0.62	0.61	0.61	0.65	0.68	0.72	0.77
Non energy output	0.78	0.80	0.81	0.81	0.82	0.82	0.81	0.81
Energy intensity (Total energy use/GDP)	-0.54	-0.66	-0.75	-0.81	-0.92	-0.97	-1.01	-1.04
Territorial CO2 emissions	0.75	0.67	0.61	0.58	0.56	0.57	0.60	0.65
Emission intensity (territorial CO2/GDP)	-0.25	-0.36	-0.43	-0.47	-0.50	-0.49	-0.46	-0.42

7.2. Disaggregation: sectors

In Section 6 we report aggregate results for GDP, employment and exports. However, in the model these variables, together with energy use in production, are generated in individual sectors. Using our preferred Bargained Real Wage closure, the short- and long-run simulation results for changes in these variables are reported at this disaggregated level in Figures 7 and 8. Appendix 3 gives a summary of key sectoral characteristics and a full description of abbreviated sector names.[20] Appendices 4 and 5 give a more detailed set of sectoral results.

Figure 7 shows that in the majority of sectors long-run employment increases as stimulus to labour demand coming through substitution- and output effects is greater than the direct negative impact of the change in labour productivity. The prominent exception is sector 28, Education, health & defence (EDU), which registers a 0.74% fall in employment. This sector is the most labour intensive sector, with 49% of its total costs falling on labour. This means that the relative price reduction is large which gives a big stimulus to its exports. However, exports are only a small share of the sector's sales: 68% of the total revenue for EDU comes from Government consumption. In the simulations reported here, Government expenditure is held constant in real terms. This means that the composite demand for the output of this sector is both price and income inelastic. If our assumptions about public consumption were to be relaxed, so that expenditure increased in line with GDP, for example, long-run employment in this sector is much more likely to rise.

Figure 7: Sectoral long-run effects of a 1.5% increase in labour productivity. In % changes from base year.

[20] Note that sectors 2 and 4, Mining & quarrying (MIN) and Other Mining & mining services (OMI), are aggregated in our results because of anomalies in the base-year data.

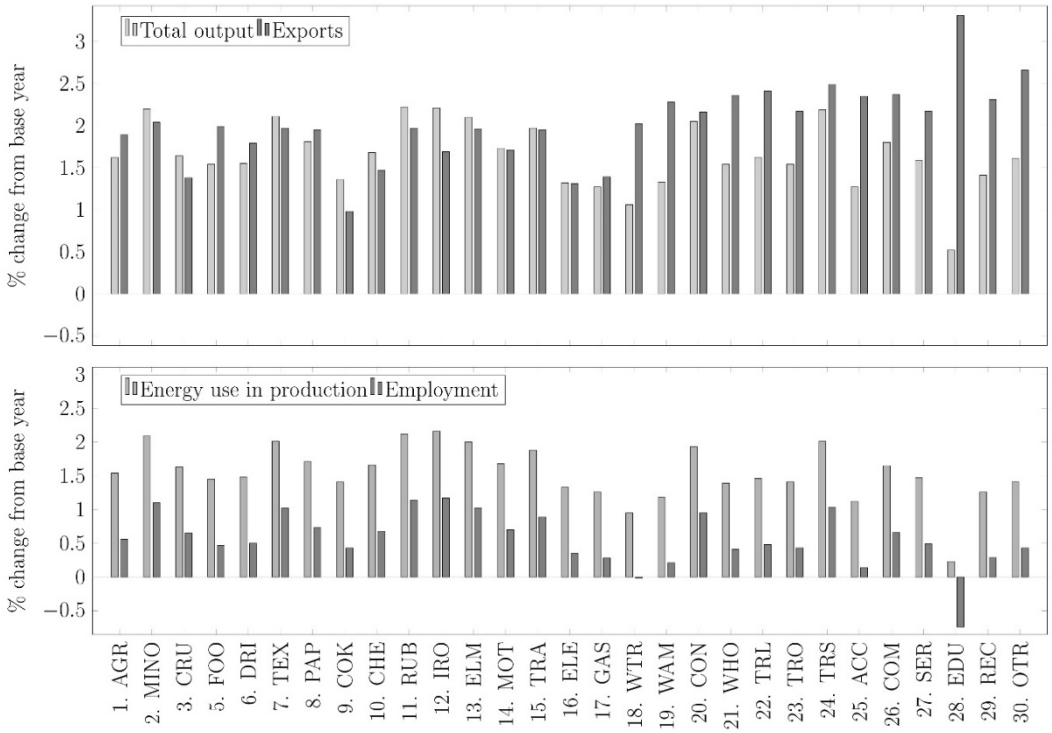
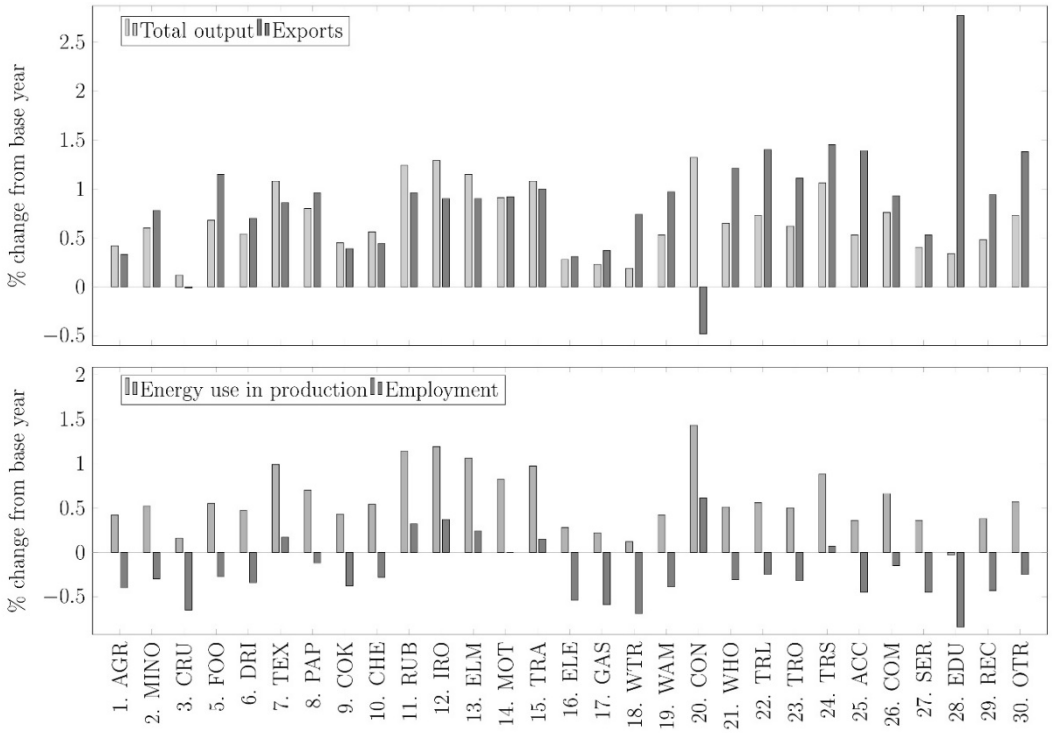


Figure 8 indicates that output and energy use increase in all sectors as result of the improvement in labour productivity. The percentage change in output tends to exceed the percentage change in energy use. Note that in the Construction sector 20 (CON) exports fall in the short run. For this sector short-run investment demand is crowding out exports. Looking at employment, it can be seen that there is no unified response to the increase in labour productivity across the sectors. Whilst aggregate employment falls in the short run, there are a number of sectors where employment increases as stimulus to labour demand coming through substitution- and output effects exceeds the direct negative impact of the change in labour productivity. All energy supply sectors see a short-run fall in employment in the short run.

Analysis presented in Ross et al. (2018) suggests that UK exporting sectors tend to be more energy intensive. This is reaffirmed by findings here. For example, sectors 21, and 27, Wholesale & retail trade (WHO), and Services (SER) are responsible for a large proportion to total exports (a combined total of 38% of total exports). These sectors benefit from the increase in competitiveness and see a strong stimulus to output and employment in both relative and absolute terms. These sectors also consume a large proportion of total energy (around 12% of total energy consumption). This expansion therefor has a significant impact on total energy use.

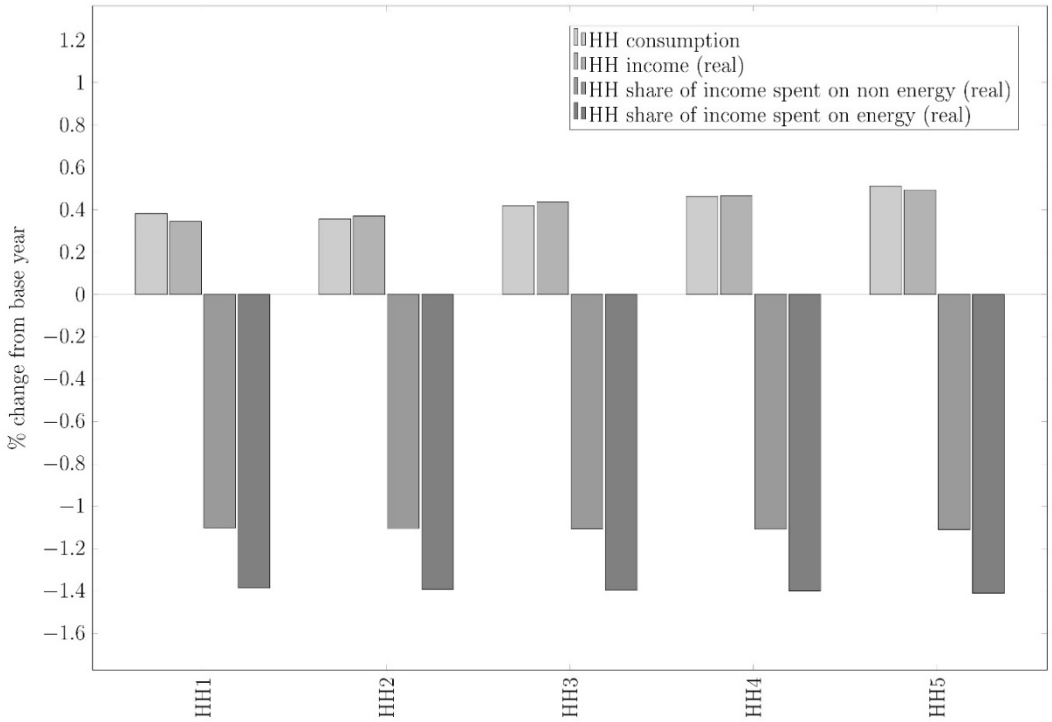
Figure 8: Sectoral short-run effects of a 1.5% increase in labour productivity. In % changes from base year.



7.3. Disaggregation: households.

Given the long-run growth in real wages and capital incomes, households see their income, and therefore also their consumption of energy and non-energy goods & services, increasing. Figure 9 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. 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 disposable income spent on energy. For this we focus on the lowest household income quintile where fuel poverty/poverty is highest (UK Government, 2017c). We find that the proportion of the lowest household income group's spending on energy falls so on that basis fuel poverty improves. Affordability (as indicated by the price of energy) increases as prices fall. As such, the increase in labour productivity has led to a number of positive impacts on energy policy impacts in terms of fuel poverty and affordability.

Figure 9: Long-run effects on Household quintiles of a 1.5% increase in labour productivity, BRW closure. In % changes from base year.



8. Summary & conclusions

Academic and policy discussions increasingly recognise the wider impacts of energy policy on the macro-economy. 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, interaction in the opposite direction, that is the impact of economic policies on the energy system, has been comparatively neglected and, in particular, there has been little system-wide analysis of the spillover effects from economic policies to the energy system (Cox et al., 2016). Moreover, such neglect might lead to inefficiencies and unforeseen conflicts (or complementarities) between energy and economic policy goals. These could be avoided by a more holistic perspective.

We have begun an analysis of the potential impacts of a successful Industrial, business and innovation policy on the UK economy and energy-system. In this paper, we investigate the system-wide effects of increases in labour productivity; in a companion paper, the effects of successful export promotion policies are outlined (Ross et al., 2018). The energy system impacts of such policies are, in large part, transmitted via their impact on the economic system. It is therefore necessary to adopt an approach that fully captures such interdependence. We do so by employing a UK computable general equilibrium (CGE) model, UK-ENVI.

At one level the results are re-assuring in that improved labour productivity has a positive long-run effect on all the major indicators of UK industrial policy, including GDP, consumption and investment. Although employment typically falls in the short run, as capacity expands through increased investment, the demand for labour increases so that employment ultimately rises above its initial level. Therefore any trade-off is simply between GDP (and economic activity generally) and short-run employment implying that the major objectives of UK industrial policy are almost wholly positively impacted by increases in labour productivity.

However, there are simultaneously significant spill-over effects to key elements of energy system, typically not helpful for achieving environmental targets. Long- and short-run total energy use and energy used in production increase in response to the improved labour productivity in all the labour market versions of our model. However, these increases are always less than the proportionate rise in GDP so that energy intensity, defined here as energy use per unit of GDP, therefore falls. Similarly, if action is not taken simultaneously to decarbonise the economy, industrial territorial CO_2 emissions increase in line with the Industrial Strategy challenge on Clean Growth, though again, emission intensity, defined as industrial territorial CO_2 emissions per unit of GDP, falls.[21] Overall, energy policymakers will be concerned with the adverse impact on emissions and although these increases are relatively small, some further adjustment of energy policies would be required to ensure that they are offset.

Neglecting these spillover effects between the energy and economic systems creates a source of inefficiency in the conduct of policy, and knowledge of their likely scale could be used to develop a more holistic, coordinated approach to policy formation and implementation. 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, the effect on the economy and energy sub-systems of other industrial policies should be investigated. We explore the likely impact of export promotion in an accompanying paper (Ross at al., 2018). Second, sectorally-targeted policies might generate further differentiated results and be better able to exploit potential complementarities or avoid trade-offs. Although there are broad similarities across sectors in the impact of a general productivity improvement, even here there is a degree of sectoral variation. Third, 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 achieving both economic and energy goals within a common modelling framework. Ultimately, we wish to explore the kinds of policy packages that are most likely to facilitate the simultaneous achievement of such goals.

[21] Note also that the trade balance improves so that part of the CO_2 emissions might be displacing emissions in other countries.

Appendices

Appendix 1

In the initial period 0, the price of labour, energy and industrial output are set equal to unity, with the price of energy and labour remaining unchanged throughout, whilst the price of the output of the industrial sector falls in response to the efficiency gain. Given that competition imposes zero profits:

$$q_0 = e_0^P + l_0 \tag{A1.1}$$

where q_0 is the industry output, e_0^P is energy use in production and l_0 is labour use, all in period zero. Equation (A1.1) is simply the initial accounting identity: the sum of all inputs equals the value of output. Note also that because the price of labour is equal to unity, the labour input is also equal to the total wage payment. Therefore:

$$w_0 = l_0 = sq_0 \tag{A1.2}$$

where s is the share of labour in output in period zero. Wage income is spent on the consumption of energy and non-energy. Using equation (A1.2), initial period energy use in consumption associated with the production in the industrial sector, in the initial period 0, e_0^C ,equals:

$$e_0^c = \beta l_0 = \beta s q_0 \tag{A1.3}$$

where β is the share of energy in consumption. Summing equations (A1.2) and (A1.3), the total energy use, e_0^T , in the initial period is:

$$e_0^T = e_0^P + e_0^C = q_0(1-(1-\beta)s) \tag{A1.4}$$

The absolute change in energy use in production, Δe^P , as a result of the increase in energy efficiency is the proportionate change times the initial value which is expressed as:

$$\Delta e^P = \dot{e}^P \cdot e_0^P = (1-s)q_0\dot{e}^P \tag{A1.5}$$

where the dot notation indicates proportionate change. Similarly the absolute change in energy use in consumption is the absolute change in wage income times the share of energy in consumption. The absolute change in wage income is the proportionate change in employment times the initial employment level. Using equation (A1.3):

$$\Delta e^C = \beta\Delta l = \beta\dot{l}.l_0 = \beta s q_0\dot{l} \tag{A1.6}$$

Summing equations (A1.5) and (A1.6) gives the absolute change in total energy:

$$\Delta e^T = \Delta e^P + \Delta e^C = q_0((1-s)\dot{e}^P + \beta s\dot{l}^P) \tag{A1.7}$$

Appendix 2

In this Appendix we verify the position of the zero welfare elasticity lines shown in Figure 2.

Appendix 2.1: $1 \geq \kappa > 0.5$

For 0J > 1, a_0 needs to be greater than 1 which requires:

$$0 > s(1-2\kappa) \tag{A2.1}$$

Expression (A2.1) must hold for $1 \geq \kappa > 0.5$.

For the intercept on the η axis to be greater than 1 requires $-a_0/a_1>1$, which implies:

$$2\kappa - 1 + \omega(1-\kappa) > 2\kappa(1-s) + w(1-\kappa) - (1-s) \rightarrow 2\kappa s > s \tag{A2.2}$$

Expression (A2.2) must hold for $1 \geq \kappa > 0.5$.

Appendix 2.2: $0.5 > \kappa \geq 0$

As the value of κ increases from zero to 0.5, the intercept on the η axis declines:

$$\frac{\partial 0F}{\partial \kappa} = \frac{\partial a_0}{\partial \kappa} = \frac{s(1-2\kappa)(\omega-2) + (1-2\kappa-\omega(1-\kappa))2s}{s^2(1-2\kappa)^2} = -\frac{1}{s^2(1-2\kappa)} < 0 \tag{A2.3}$$

0F is zero when:

$$1 - 2\kappa - \omega(1-\kappa) = 0 \rightarrow 0.5 \geq \kappa = \frac{1-\omega}{2-\omega} \geq 0 \tag{A2.4}$$

Using (A2.1), for 0M < 1 requires

$$0 < s(1-2\kappa) \tag{A.2.5}$$

This always holds in this case.

Appendix 3: 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

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 4: Sectoral long-run effects of a 1.5% increase in labour productivity. 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	1.62	-0.93	0.56	1.81	-0.68	1.89	1.66	1.66	0.41	1.54
2. MIN + 4.OMI	2.20	-1.00	1.10	2.44	-0.96	2.04	2.21	2.21	0.36	2.09
3. CRU	1.64	-0.69	0.65	1.79	-0.06	1.38	1.75	1.75	0.39	1.63
5. FOO	1.54	-0.98	0.47	1.90	-0.94	1.99	1.57	1.57	0.42	1.45
6. DRI	1.55	-0.88	0.50	1.82	-0.69	1.79	1.60	1.60	0.40	1.48
7. TEX	2.11	-0.97	1.02	2.43	-0.36	1.97	2.13	2.13	0.43	2.01
8. PAP	1.81	-0.96	0.73	2.13	-0.66	1.95	1.83	1.83	0.43	1.71
9. COK	1.36	-0.49	0.43	1.84	0.07	0.98	1.53	1.53	0.33	1.41
10. CHE	1.68	-0.73	0.68	1.98	0.00	1.47	1.78	1.78	0.38	1.66
11. RUB	2.22	-0.97	1.14	2.57	-0.16	1.97	2.25	2.25	0.42	2.12
12. IRO	2.21	-0.83	1.17	2.62	0.18	1.69	2.28	2.28	0.40	2.16
13. ELM	2.10	-0.97	1.02	2.43	-0.25	1.96	2.13	2.13	0.43	2.00
14. MOT	1.73	-0.84	0.70	2.12	-0.46	1.71	1.80	1.80	0.41	1.68
15. TRA	1.97	-0.96	0.89	2.32	-0.50	1.95	2.00	2.00	0.43	1.88
16. ELE	1.32	-0.65	0.35	1.59	-0.16	1.31	1.45	1.45	0.15	1.33
17. GAS	1.27	-0.69	0.28	1.57	-0.27	1.39	1.38	1.38	0.16	1.26
18. WTR	1.06	-0.99	-0.02	1.20	-1.17	2.02	1.07	1.07	0.42	0.95
19. WAM	1.33	-1.12	0.21	1.54	-1.14	2.28	1.30	1.30	0.44	1.18
20. CON	2.05	-1.06	0.95	2.27	-0.58	2.16	2.05	2.05	0.43	1.93
21. WHO	1.54	-1.16	0.41	1.79	-1.31	2.36	1.51	1.51	0.47	1.39
22. TRL	1.62	-1.18	0.48	1.89	-1.19	2.41	1.58	1.58	0.47	1.46
23. TRO	1.54	-1.07	0.43	1.83	-1.90	2.17	1.53	1.53	0.45	1.41
24. TRS	2.19	-1.22	1.03	2.47	-0.81	2.49	2.13	2.13	0.49	2.01
25. ACC	1.27	-1.15	0.14	1.53	-1.93	2.35	1.24	1.24	0.47	1.12
26. COM	1.80	-1.17	0.66	2.03	-1.09	2.37	1.77	1.77	0.47	1.65
27. SER	1.59	-1.07	0.49	1.76	-1.00	2.17	1.59	1.59	0.44	1.47
28. EDU	0.52	-1.61	-0.74	0.70	-2.39	3.31	0.35	0.35	0.56	0.23
29. REC	1.41	-1.13	0.29	1.60	-1.37	2.31	1.38	1.38	0.46	1.26
30. OTR	1.61	-1.30	0.43	1.81	-1.50	2.66	1.53	1.53	0.50	1.41

Appendix 5: Sectoral short-run effects of a 1.5% increase in labour productivity. 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	0.42	-0.16	-0.40	0.39	0.07	0.33	-	1.53	-0.14	0.42
2. MIN + 4.OMI	0.60	-0.39	-0.30	0.72	-0.88	0.78	-	2.07	-0.14	0.52
3. CRU	0.12	0.00	-0.65	0.09	0.34	-0.01	-	0.62	-0.18	0.16
5. FOO	0.68	-0.57	-0.27	1.01	-0.78	1.15	-	1.72	-0.06	0.55
6. DRI	0.54	-0.35	-0.34	0.61	-0.35	0.70	-	1.59	-0.10	0.47
7. TEX	1.08	-0.42	0.17	1.23	0.02	0.86	-	3.44	-0.07	0.99
8. PAP	0.80	-0.48	-0.12	0.99	-0.42	0.96	-	2.38	-0.06	0.70
9. COK	0.45	-0.19	-0.38	0.84	-0.10	0.39	-	1.36	-0.11	0.43
10. CHE	0.56	-0.22	-0.28	0.60	0.17	0.44	-	1.94	-0.12	0.54
11. RUB	1.24	-0.48	0.32	1.46	0.03	0.96	-	3.90	-0.07	1.14
12. IRO	1.29	-0.45	0.37	1.55	0.17	0.90	-	3.98	-0.08	1.19
13. ELM	1.15	-0.45	0.24	1.31	0.14	0.90	-	3.58	-0.07	1.06
14. MOT	0.91	-0.46	0.00	1.20	-0.29	0.92	-	2.61	-0.06	0.82
15. TRA	1.08	-0.50	0.15	1.32	-0.18	1.00	-	3.24	-0.06	0.97
16. ELE	0.28	-0.15	-0.54	0.34	0.02	0.31	-	0.96	-0.29	0.28
17. GAS	0.23	-0.18	-0.59	0.41	-0.04	0.37	-	0.72	-0.29	0.22
18. WTR	0.19	-0.37	-0.69	0.25	-0.57	0.74	-	0.23	-0.11	0.12
19. WAM	0.53	-0.48	-0.39	0.63	-0.54	0.97	-	1.25	-0.08	0.42
20. CON	1.32	0.24	0.61	1.11	1.88	-0.48	-	4.65	-0.23	1.43
21. WHO	0.65	-0.60	-0.31	0.83	-0.82	1.21	-	1.64	-0.04	0.51
22. TRL	0.73	-0.69	-0.25	0.93	-0.91	1.40	-	1.81	-0.02	0.56
23. TRO	0.62	-0.55	-0.32	0.85	-1.23	1.11	-	1.59	-0.04	0.50
24. TRS	1.06	-0.72	0.07	1.30	-0.71	1.45	-	3.03	-0.01	0.88
25. ACC	0.53	-0.69	-0.45	0.75	-1.40	1.39	-	1.02	-0.02	0.36
26. COM	0.76	-0.46	-0.15	0.85	-0.37	0.93	-	2.31	-0.07	0.66
27. SER	0.40	-0.26	-0.45	0.43	-0.20	0.53	-	1.32	-0.12	0.36
28. EDU	0.34	-1.36	-0.84	0.57	-2.27	2.77	-	-0.56	0.12	-0.03
29. REC	0.48	-0.47	-0.43	0.57	-0.66	0.94	-	1.22	-0.07	0.38
30. OTR	0.73	-0.68	-0.25	0.86	-0.90	1.38	-	1.83	-0.02	0.57

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