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Research Article

Examining the Interplay of Labour Productivity Policies and Industrial-Energy-Environmental Policy Goals

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The academic and policy-oriented literature increasingly quantifies the wider effects of energy policy on the macroeconomy. However, the spillovers from economic policies to energy use are less frequently recognised, meaning that many policymakers who strive to improve productivity whilst simultaneously targeting emission reduction fail to consider these interactions. This paper addresses this issue by using simulation results generated by introducing an exogenous increase in labour productivity in a computable general equilibrium model calibrated with data from the United Kingdom. Theoretical analysis suggests that increasing labour productivity can have positive or negative effects on employment levels and energy use. However, the simulation results show that in the context of a developed open economy, improved labour efficiency will increase employment, a key policy objective, but simultaneously increase energy use. A key policy implication is that this work highlights the need for policy frameworks that explicitly acknowledge and quantify the interconnections between national economic policy strategies and energy policy objectives. Secondly, it shows that in practice, policies to reduce carbon emissions need to be strengthened alongside policies to improve productivity successfully implemented.

1. Introduction

The United Kingdom (UK) government has identified two key priorities for the economy as it emerges from the COVID-19 pandemic. Firstly, there is a goal to improve labour productivity to match other European countries such as Germany and France [1]. Secondly, there is a commitment to achieving net-zero carbon emissions by 2050 [2]. These twin objectives align with the economic and environmental policies of many other countries.

There is a substantial literature around the growth potential of low-carbon energy technologies [3–6]. Many governments have launched green industrial plans or have made "green jobs" a crucial part of their wider industrial policies [7–12]. Nevertheless, the influence of general economic policies on the energy system has received less attention in research, particularly in a system-wide context [13–15]. Most studies that exist are limited to certain economic policy categories (such as international trade or transportation) or focus on how economic policy measures, such as air travel taxes, can contribute to achieving environmental/energy goals [16–23].

In this paper, we focus on how an increase in labour productivity, which is a key objective of national economic strategies, can affect employment and energy use. This is particularly relevant in the current policy landscape of economic rebuilding after COVID-19 and the associated resurgence of industrial policies [24]. We identify an improvement in labour productivity as implying a decrease in the number of workers needed to provide the given level of labour services. This, in turn, has a direct negative impact on employment. However, the reduction in production costs improves competitiveness, leading to increased output and a subsequent indirect demand for both energy and labour.

Additionally, increased labour productivity leads to a substitution of energy for labour in the production process. Finally, changes in employment levels also influence household income, which, in turn, impacts household energy consumption. It is evident that economic policies aimed at enhancing labour productivity have multiple endogenous economic responses that influence employment levels and overall energy use.

In this paper, we present an analytical model which suggests that labour-augmenting productivity improvements can be associated with any combination of positive or negative employment and energy use effects, which depend upon the values of key demand and substitution parameters. In short, an improvement in labour productivity may therefore potentially aid the achievement of both industrial and environmental policy goals, but it may also make it more difficult, requiring compensating policies elsewhere to ensure delivery of net-zero obligations.

To empirically examine this proposition, we use a well-established multisectoral computable general equilibrium (CGE) model specific to the United Kingdom (UK). Whilst our empirical analysis focuses on the UK, the analytical model is applicable to other regions and countries, provided the necessary data is available. The individual elements of the model, such as the production, consumption, and income distribution relationships, are driven by standard economic theory. The initial structural characteristics, such as the economy's industrial composition and the capital, labour, and intermediate intensities of individual sectors, are calibrated to be similar to other developed, relatively open economies. The behavioural relationships concerning, for example, labour market behaviour, are parameterised using available econometric results. Whilst the specific output of these analyses is likely to vary from country to country, the overall findings and the ensuing policy suggestions are applicable to all countries and regions with a similar economic structure and policy objectives.

Our paper makes two important contributions. Firstly, we highlight the significance of frameworks that explicitly acknowledge and quantify the spill-over effects of national economic policy strategies on energy policy goals. This recognition is crucial in understanding the broader implications of economic policy choices, not only for economic outcomes but also for wider objectives pertaining to energy use and the transition to net-zero. Secondly, we underscore the importance of these spill-over effects, emphasising the need for policymakers to recognise the far-reaching consequences of their economic policy decisions. Our findings indicate that, across a wide range of plausible parameter values and labour market options, the long-term outcome of labour productivity-enhancing policies is likely to result in increased energy use. This insight further reinforces the need for careful consideration and integration of energy policy objectives within efforts to enhance labour productivity.

The structure of this paper is as follows. In Section 2, we present the simplified model used to derive the theoretical background and analytical results. Section 3 provides an overview of the empirical dynamic energy-economy-environment CGE model and the simulation approach employed. The simulation results are presented in Section 4, and finally, Section 5 concludes the study.

2. Theoretical Background

In this section, we present a basic, stripped-down model of the economy to underpin the theoretical background. This identifies key parameter values that determine the qualitative and quantitative changes in those variables that accompany labour productivity improvements. Results from this analysis are used to aid interpretation of the substantially more detailed CGE simulation outcomes reported in Section 4.

In this basic analytical model, a perfectly competitive industry uses two inputs, labour and energy. Its sole output is an export good, and all energy is imported. There are zero profits so that wages are the sole component of household income, which is spent on energy for domestic use and an imported consumption good. The prices of energy, imported consumption good, and labour are fixed. This implies that the share of energy in household consumption remains constant and that real and nominal household income is proportionate to employment. The export good faces a conventional demand curve so that its output rises as price falls (one way of interpreting these assumptions is that they allow production to be treated as though it were in partial equilibrium whilst making household income and consumption 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 household consumption ($\dot{e}^c$). Given the fixed prices, the proportionate increase in household energy consumption equals the proportionate change in employment $\dot{l}$. This gives

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

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

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

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

A primary concern is Γ^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 found by differentiating equation (1) with respect to labour efficiency giving

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

In equation (3), Γ^p and Γ^l are the elasticities of energy in production and employment, both with respect to a change in labour efficiency. Using results given in Figus et al. [25], these input-use elasticities can be expressed as functions of the elasticity of demand for the product (η), the elasticity

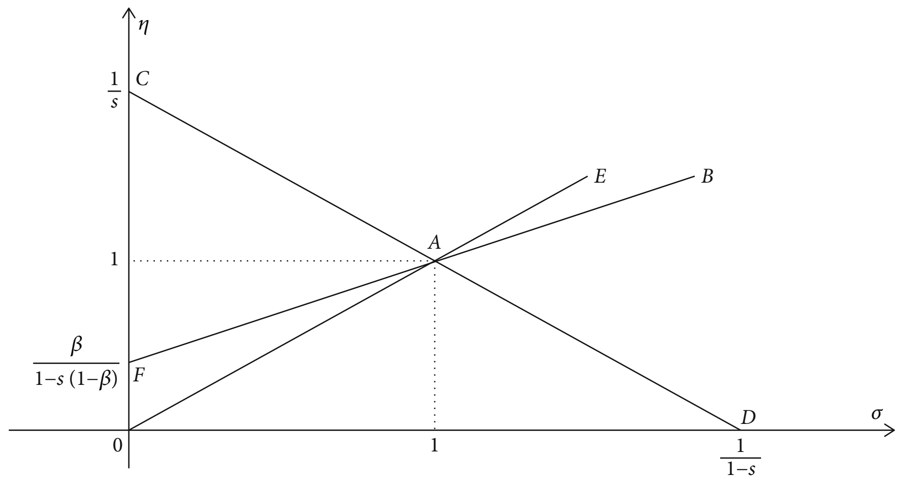

Figure 1: Parameter combinations giving zero energy use and employment elasticities with respect to labour efficiency changes. 0AE identifies zero production energy use, FAB zero total energy use, and CAD total employment elasticities.

of substitution between labour and energy in production (σ), and the share of labour in production (s):

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

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

Substituting equations (2), (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):

$$\Gamma^{T} = s\eta - \left[\frac{(1-s)s(1-\beta)}{1-(1-\beta)s}\right]\sigma - \frac{s\beta}{1-s+s\beta}. \quad (6)$$

Equations (4)–(6) are central for the analysis in identifying the reaction of the three key variables e^T, e^p, and l in increased labour efficiency. Although the share parameters are considered in, we primarily focus on the roles played by η and σ.

Equations (7)–(9) are derived by setting Γ^p, Γ^l, and Γ^T equal to zero in equations (4)–(6) and rearranging. These equations identify the combinations of the demand and substitution elasticities η and σ, for which changes in the labour productivity will generate no change in energy use in production, employment, and total energy use, respectively.

$$\eta = \sigma, \quad (7)$$

$$\eta = -\frac{(1-s)}{s}\sigma + \frac{1}{s}, \quad (8)$$

$$\eta = \left[\frac{(1-s)(1-\beta)}{1-(1-\beta)s}\right]\sigma + \frac{s\beta}{1-s+s\beta}. \quad (9)$$

These expressions correspond to the lines 0AE, FAB, and CAD in Figure 1.

Begin with equation (7). This is represented by the line 0AE and shows the elasticity values which give an unchanged energy use in production after an improvement in labour efficiency. Note that this line passes through the origin (0, 0) where the elasticities of both input substitution and product demand are zero. This combination of elasticities would generate no change in the energy intensity of production, nor output, as labour productivity increases. However, with a positive value for σ, the energy intensity of production falls as labour is substituted for energy in production, and with a positive value for η, output will rise, where $\sigma = \eta$; these two opposing influences cancel, where $\sigma > \eta$, which covers all the elasticity combinations below, and to the right of line 0AE, energy use in production will fall as labour efficiency increases. For parameter combinations in the area above and to the left of the line 0AE, energy use increases.

Equation (8) shows the (σ, η) combinations where employment is unchanged after a rise in labour productivity. This is represented by the line CAD in Figure 1. The direct impact on employment of the labour productivity increase is negative—less physical labour is needed to produce the same output. With the (σ, η) combination (0, 0), employment must fall. However, in this case, higher values of both σ and η will mitigate the employment loss or lead to an employment gain. With elasticity combinations to the left and below the line CAD, a labour productivity increase generates a fall in employment; above and to the right, it produces an employment increase. Further, it is straightforward to show that the intercepts 0C and 0D both take values greater than one.

Note that both lines 0AE and CAD passes through the point A where both elasticities σ and η are equal to 1. Where the elasticity of demand is one, the total value of sales does not vary as the product price varies, and when the elasticity of substitution equals one, the share of an input in the value of sales is unchanged as the price of that input rises or falls.

Therefore, where both elasticities are unity, the level of expenditure on both inputs is unchanged because of the efficiency improvement in labour. Given that the price of both inputs in physical units is fixed, energy use and employment do not change.

There is a direct interest in the employment outcome as a measure of the success of the industrial policy. However, we are also interested in employment from the viewpoint that any change in domestic income will increase household energy use. Given the share parameters s and β, equation (9) identifies the product demand and input substitution elasticities that generate zero change in total energy use. This is represented by the line FAB in Figure 1, which is the weighted sum of the lines 0AE and CAD. It is a straight line with a positive slope and intercept, 0F, on the η axis. The values of both the slope and intercept are less than one, and the line passes through the point A. Elasticity combinations above the line FAB generate increased total energy use when labour productivity rises, whilst for those below, total energy use falls.

Figure 1 identifies six possible outcomes for labour use, energy use in production, and total energy use. (There are $2^3 = 8$ conceivable 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.) 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 is designated by positive signs, then the six areas are associated with the following outcomes: CAE (+, +, +), EAB (+, -, +), BAD(+, -, -), DA0 (-, -, -), FA0 (-, +, -), and FAC (-, +, +).

The analytical model focuses on a small range of key relationships that are likely to play an important part in determining the response of the economy and the energy system to improvements in labour efficiency. Its primary role is to show the wide range of possible employment and energy-use outcomes resulting from a general improvement in labour productivity. However, this has been achieved through extreme simplification and the suppression of effects which could have a significant impact on the result, but, therefore, we extend the analysis using simulation from a CGE model.

The computable general equilibrium (CGE) model, UK-ENVI, we employ contains a strong theoretical base, broadly consistent with the analytical approach in this section. However, it allows a wider range of economic activity and greater degree of disaggregation. For example, investment and government expenditure are now identified as elements of final demand for domestic output in addition to exports. A wider range of productive inputs is incorporated, including capital and intermediate inputs, and 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 the consumer price index (CPI) and is 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.

3. Model and Data

UK-ENVI was purpose-built to capture the interdependence of the energy and nonenergy subsystems. Versions of this model have been employed previously to analyse the impacts of increased energy efficiency, carbon taxes, and other fiscal policies [25–29]. 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 brief description of the main characteristics of the model, with a particular emphasis on the linkages between the economic and energy subsectors.

The UK-ENVI model has 30 separate production sectors, including the main energy industries that encompass the supply of coal, refined oil, gas, and electricity. We also identify the transactions of the United Kingdom (UK) households (by income quintile), the UK government, imports, exports, and transfers to and from the rest of the world (ROW). The UK social accounting matrix (SAM) constitutes the core dataset of the UK-ENVI model. Emonts-Holley et al. [30] give a detailed description of the methods employed to construct these data and the SAM is available for download at 10.15129/bf6809d0-4849-4fd7-a283-916b5e765950 (the latest data available at the time of writing). However, other information is required to complete the specification of the model. This typically includes 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 carbon dioxide (CO_2) emissions are calculated and linked to the CGE sectoral primary fuel use according to Allan et al. [31].

3.1. 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. The solution of the household optimisation problem gives the optimal time path for consumption of the bundle of goods.

To capture information about household energy consumption, total consumption is allocated within each period between energy and nonenergy goods in accordance with a constant elasticity of substitution (CES) function. The consumption of energy is then divided into two composite goods: coal and refined oil and electricity and gas. These in turn split into the four energy uses, refined oil, coal, electricity, and gas, through a nested CES structure. Note that the share of coal consumed by households represents less than 0.01% of total energy consumption. Moreover, we assume that the individual can consume goods produced both domestically and imported, where imports are combined with domestic goods under the assumption of imperfect substitution [32].

3.2. Production, Productivity, and Investment. In each industry sector, the production structure is characterised by a capital, labour, energy, and material- (KLEM) nested CES production function. The combination of labour and capital forms value added, whilst energy and materials make up intermediate inputs. In turn, the combination of intermediates and value added comprises total output in each sector. The value-added production function for each activity (i) is given as

$$VA_{i,t} = \left[a_i(\gamma L_{i,t})^{(\varepsilon_i-1)/\varepsilon_i} + (1-\alpha_i)(K_{i,t})^{(\varepsilon_i-1)/\varepsilon_i}\right]^{-(\varepsilon_i-1)/\varepsilon_i}, \quad (10)$$

where L and K are the labour and capital inputs, γ is the labour productivity parameter (initially set to 1.0), and ε is the elasticity of substitution between capital and labour (set to 0.3).

An improvement in labour efficiency is known in the economic growth literature as Harrod-neutral technical change. It is introduced by increasing the labour-augmenting efficiency parameter γ. Following Hayashi [33], the optimal time path of investment is derived by maximising the value of firms subject to a capital accumulation function.

3.3. 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. This case effectively implies an infinitely elastic supply of labour at the base-period real wage. Whilst a useful benchmark that also represents the outcome where there is costless migration, it is not our most favoured closure.

Our preferred treatment of the labour market embodies a wage curve [34]. This approach is supported by extensive empirical evidence 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:

$$\ln\left[\frac{w_t}{cpi_t}\right] = \rho - \varphi \ln(u_t), \quad (11)$$

where w_t and cpi_t are the post-tax wage and consumer price index in time period t, respectively; ϕ is the elasticity of the real wage with respect to the rate of unemployment (u_t), and ρ is a parameter calibrated to the initial equilibrium steady state. In the simulations reported in Section 4, the working population is assumed to be fixed, and this model implies the presence of involuntary unemployment, with bargained real wage lying above the competitive supply curve for labour.

Finally, conventional national CGE models often make the simplifying assumption of an entirely exogenous labour supply (ELS), with population, participation, and unemployment rates fixed. The exogenous labour supply and the fixed real wage closures are limiting cases with real wage elasticities of zero and infinity, respectively. The bargained real wage closure is an intermediate case in which the effective level of employment varies positively with the real consumption wage. (Whilst 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.)

3.4. Government. In the simulations reported in Section 4, government expenditure is held constant in real terms. Government income reflects revenues from all taxes (and foreign transfers, which are taken to be exogenous). (Note that the income tax is levied at a fixed rate τ which is calibrated to the base-year dataset.) The government budget surplus is equal to the difference between government income and government spending.

3.5. Simulation Strategy. The present paper quantifies, through simulation, the effects on key elements of the economic and energy systems of a successful economic growth policy, specifically the impact of increasing labour productivity in line with the UK's plan for growth [35]. We adopt a rather broad-brush interpretation of the productivity-enhancing aspects of such a strategy and impose an exogenous (and costless), permanent 1.5% step increase in labour productivity across all production sectors. (Modelling the direct impact of such a strategy as a step increase in efficiency is a simplification. A more gradual introduction will affect the time path of adjustment but does not affect the long-run equilibrium. Figus and Swales [36] discuss what is meant by a costless increase in efficiency.) This involves exogenously increasing the value of the parameter γ, in equation (10), which determines the relationship between inputs of capital and labour in the production of value added. In all sectors, this parameter is permanently raised from an initial value of 1 to a value of 1.015. The 1.5% increase in labour productivity is broadly in line with the difference between the present UK and average European Union (EU28) labour productivity levels [37].

The model is calibrated to an initial long-run equilibrium so that if it is run forward with no disturbance in each period, it simply replicates the base-year dataset. The results presented here, unless otherwise specified, are expressed as percentage changes in the endogenous variables relative to this unchanging equilibrium so that they are directly attributable to the exogenous shocks to labour productivity.

Whilst 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

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
Gross domestic product (GDP)	1.96	1.66	1.45	0.53	0.68	0.91
Consumer price index (CPI)	-1.32	-1.12	-0.98	-0.45	-0.50	-0.60
Unemployment rate (pp difference)	-0.49	-0.20	0.00	0.59	0.36	0.00
Total employment	0.52	0.21	0.00	-0.63	-0.38	0.00
Nominal gross wage	-1.32	-0.89	-0.60	-0.45	-0.89	-1.63
Real gross wage	0.00	0.23	0.38	0.00	-0.40	-1.03
Household 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	1.27	1.07	0.94	0.12	0.23	0.38
Electricity	1.35	0.93	0.81	0.06	0.17	0.32
Gas	1.10	1.01	0.89	0.10	0.22	0.37
Energy use in production	1.66	1.40	1.22	0.29	0.40	0.57
Energy consumption	0.81	0.68	0.59	-0.11	-0.05	0.02
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)	-0.69	-0.59	-0.51	-0.41	-0.45	-0.53
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

Note: FRW = fixed real wage; BRW = bargained real wage; ELS = exogenous labour supply.

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, and are again equal to their new desired levels. Simulation results are reported for the three labour market closures outlined in Section 3.3.

4. Simulation Results

The simulation results reflect the basic analysis outlined in Section 2 but incorporate additional economic interaction suppressed in the stripped-down approach. We take as a benchmark the long-run results generated under the fixed real wage variant of the computable general equilibrium (CGE) model. These results are presented in the first column of Table 1 where the economy has fully adjusted to the efficiency disturbance. As noted earlier, the fixed real wage labour market closure is chosen to minimise the endogenous variation in relative prices.

4.1. 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 2, 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 1.27%, respectively. Our default production substitution elasticities are relatively low, whilst the output demand elasticities are high, especially for exports. We compare the characteristics of the CGE framework with the analytical model given in Section 2 and reflect on some of the differences in these benchmark results.

There are two clear differences between the CGE and the analytical model. The first is that in the analytical model, production occurs with just two inputs, labour and energy, whereas the CGE model adopts a capital-labour-energy-material (KLEM) production function, incorporating capital and intermediates as additional inputs. A second major difference is that in the analytical model, we make a clear division between exports and imports: all energy and consumer goods are imported; all domestic output is exported. In the CGE model, more realistic conditions hold, consistent with the base-year social accounting matrix (SAM). Domestic production, which includes some energy output, is split between exports, domestic intermediates, household consumption, and capital goods. Similarly, imports are spread amongst the same demand categories.

On closer inspection, the differences between the analytical and benchmark computable general equilibrium (CGE) model are not that prominent. This is because intermediates

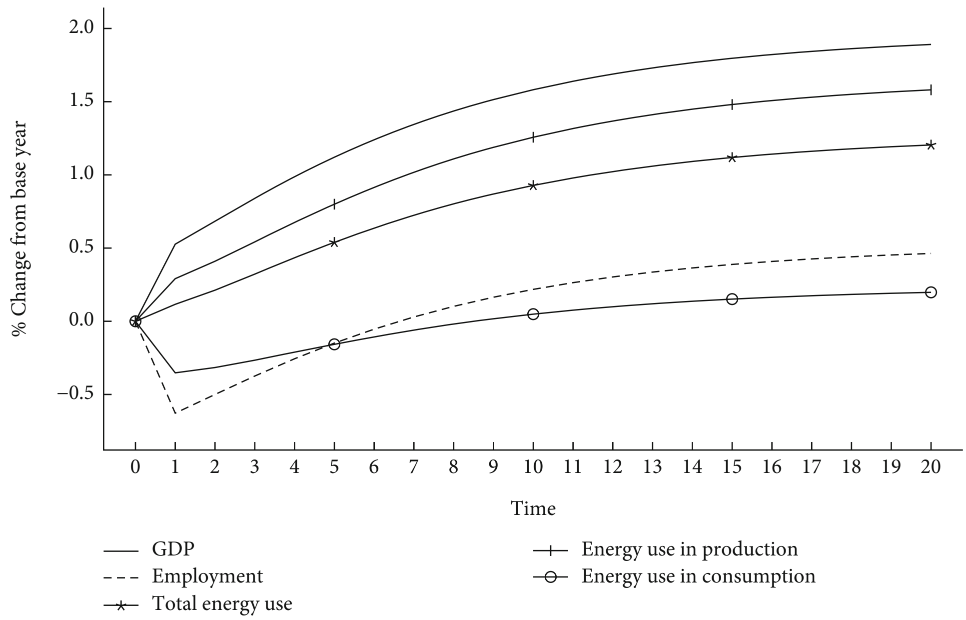

Figure 2: Aggregate transition path for GDP, employment, and energy use/consumption of a 1.5% increase in labour productivity, fixed real wage closure. In % changes from base year.

and capital goods are themselves produced means of production which themselves embody labour. Any labour productivity increase which reduces the price in a sector will further reduce the price of any commodity that uses that output as an intermediate. This also includes the production of capital goods. Similarly with real wages held constant, a fall in domestic prices will be further reflected in lower nominal wages, and again, this contributes to a downward price multiplier effect.

Therefore, in the benchmark simulation, we observe a 1.32% decrease in the consumer price index (CPI) and nominal wage. This implies that the price of labour in efficiency units has fallen by 2.82% (1.5% + 1.32%) rather more than the 0.89% fall in the price of energy. We therefore expect both a stimulus to output and a substitution either directly or indirectly of labour for energy. Exports increase by 2.38%, and there is a 1.14% reduction in imports. This stimulates increases in investment (1.68%), and household consumption (0.53%). Total energy use and energy use in production both rise but not as rapidly as gross domestic product (GDP). The energy intensity of production therefore falls.

4.2. Short-Term Benchmark Result. In the benchmark simulation, the capital stock has fully adjusted in all sectors to the productivity shock. However, in any one time period, the capital stock is fixed, both in aggregate and in its distribution across sectors, but in each industry, these stocks are adjusted through depreciation and net investment between periods. The evolution for key variables with the fixed real wage closure is shown in Figure 2. The first period (short run) values for a wider range of variables are reported in the fourth data column in Table 1.

The most striking aspect of the adjustment path is the sharp, 0.63%, reduction in employment in period 1, whilst GDP increases by 0.53%. This reflects the direct labour-saving characteristic of the productivity increase. The period 1 reduction in employment is accompanied by falls in labour income, household income, consumption, and household energy use. However, total energy use increases right from the start, and household energy use is above its base-year value by period 2.

The fixed capital stock limits the expansion of the economy, and whilst GDP increases in period 1, it only reaches just over a quarter of its long-run increase of 1.96%. As capacity expands, employment rises, but it is not until period 7 that total employment is above its base-year value. The increase in capital stock eases supply constraints, allowing prices to fall and exports to rise, and this stimulates consumption, investment, and import substitution. In period 1, energy prices fall by less than CPI (0.20% against 0.45%) and very clearly compared to the cost of labour in efficiency units which declines by 1.95%. There is clearly substitution against energy with total energy use increasing by only 0.12% in period 1.

Figure 2 shows the time paths for the adjustments in GDP, employment, total production, and energy use consumption. These endogenous variables take a significant time to adjust fully, though all are close to their long-run equilibrium values by period 20. The lines that track the evolution of the three energy use measures lie between the gross domestic product (GDP) and employment functions. By year 10, employment has increased by around 0.2%, total energy use by 1%, and GDP 1.5%. An untargeted increase in labour productivity across the economy will ultimately increase GDP by an even greater amount, with total energy growth lower, but still substantial. Employment initially falls, and subsequent growth is sluggish. Whilst energy use as a share of GDP falls, energy use per worker increases.

4.3. Alternative Labour Market Closures. The benchmark fixed real wage (FRW) model holds the real wage constant. This is useful as a benchmark model in that all price changes flow directly from the labour-augmenting change in technology. However, as outlined in Section 3, there are alternative labour market specifications, and the nature of the labour market will affect the policy effectiveness of the efficiency improvement. In these alternative cases, the real wage adjusts to changes in labour demand. Our preferred labour market closure is the bargained real wage (BRW).

From Table 1, with the fixed real wage (FRW), GDP, employment, and energy use all experiences a long-run increase. The introduction of the bargained real wage cushions, but does not reverse, the impact of the efficiency shock. In particular, the flexibility of the wage limits the absolute size of any employment change, either positive or negative, and the long-run improvement in competitiveness is reduced. The long-run increases in GDP, employment, and energy use, at 1.66%, 0.21%, and 1.07%, respectively, 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 whilst 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 immediate short-run (period 1) results, the cushioning effect of a degree of wage flexibility operates in the opposite direction for those variables tracking aggregate economic activity. The absolute size of the reduction in prices is greater as the real wage falls, so that competitiveness and gross domestic product (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-run changes are 0.68%, -0.38%, 0.23%, 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, together with a fixed unemployment rate. In these cases, total flexibility in the wage is required 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 than under the other two closures. Again, in the long run, the opposite applies. The real wage increases by 0.38%, even further than under the bargained real wage to choke off the increased demand for labour.

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.

4.4. Sensitivity to Substitution Elasticities. A primary concern of this research is the impact of growth policies on energy use. We demonstrate, in the very stripped-down model of Section 2, that an increase in general economic activity driven solely by improved labour efficiency can be accompanied by a fall in energy use. However, in none of the simulations reported in Table 1 does this occur. In this section, we test the sensitivity of energy use to changes in the elasticity of substitution in production and consumption to see whether, in the more complete computable general equilibrium (CGE) simulation model, if substitution elasticities are increased enough, energy use can fall together with an increase in employment.

We again impose a 1.5% increase in labour productivity, holding the real wage constant. However, in each simulation, the Armington trade elasticities are now set to unity. All the other production and consumption elasticities, for example, those used in equations (4) and (5) in Section 2, are set to the same value. We identify these production and consumption elasticities in Table 2 as σ, and they range from 0.3 to 3.5. In Table 2, we report the variation in the impact of the efficiency improvement as inputs in production and commodities in consumption become more perfect substitutes for one another.

It is useful to begin by focusing on the changes in employment and energy use generated by the analytical model. With a unitary export elasticity, these variables should change monotonically with the elasticity of substitution, with employment increasing and energy use falling. Moreover, the variation in both, relative to their base-year values, should approach zero as σ approaches one. This very closely approximates the observed simulated employment change. Where σ equals 0.3, long-run employment falls by 0.37%, whilst at values for σ greater than 1, employment grows, and for the value 3.5, the corresponding employment change is 1.31%.

The variation in energy use follows less closely the analytical model. Although the change in total energy use generally falls as the value of σ increases, it still takes a positive value of 0.17% where the substitution elasticities equal one. Further, we also fail to find energy use falling below its initial level for any values of σ, and the change in energy use shows a very slight increase, from 0.08% to 0.09%, as the elasticity changes from 3.0 to 3.5.

For energy use, there are three important differences between the analytical model of Section 2 and the CGE used to produce the simulations reported in Table 2. First, in the analytical model, energy is a nonproduced input whose price does not change. This compares to the CGE model where energy is a domestically produced commodity whose price increases relative to the consumer price index but will fall relative to imports. Second, in the analytical model, energy is the only input in production, apart from labour. However, in the CGE capital, other domestically produced intermediates and imports also enter production. Third, the analytical

Table 2: Sensitivity analysis of the long-run effects of a 1.5% increase in labour productivity given as % changes from base year. Variation in the elasticities of substitution in production and consumption, σ, with export elasticity of demand, η, equal to 1.

	Armington ($n = 1.0$)							
σ	0.30	0.70	1.00	1.30	2.00	2.50	3.00	3.50
Gross domestic product (GDP)	1.00	1.02	1.04	1.05	1.06	1.07	1.07	1.07
Consumer price index (CPI)	-1.31	-1.36	-1.39	-1.43	-1.49	-1.54	-1.58	-1.61
Total employment	-0.37	-0.14	0.03	0.19	0.56	0.81	1.06	1.31
Nominal gross wage	-1.31	-1.36	-1.39	-1.43	-1.49	-1.54	-1.58	-1.61
Households consumption	-0.14	-0.08	-0.04	-0.01	0.07	0.13	0.18	0.23
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 energy use	0.39	0.24	0.17	0.13	0.08	0.08	0.08	0.09
Energy use in production	0.64	0.46	0.37	0.31	0.21	0.17	0.14	0.11
Household energy consumption	-0.31	-0.39	-0.42	-0.43	-0.42	-0.39	-0.34	-0.30
Energy output prices	-0.88	-1.00	-1.08	-1.14	-1.27	-1.34	-1.41	-1.46

model has only one produced output; there are no sectoral effects whereas the CGE has 30 domestic production sectors.

Table 2 separately reports energy use in production and household consumption. We consider consumption first. In the analytical model, household energy use simply tracks employment; as employment increases, so does household income and domestic energy consumption. However, because in the CGE model the energy price falls less than the CPI, there is substitution away from energy by households. This means that as the elasticities of substitution in production and consumption increase, two opposing forces operate on household energy consumption: a positive income but negative substitution effect. In Table 2, as σ increases up to 1.30, the additional negative substitution effects dominate; as σ increases from 0.30 to 1.30, household energy use falls from -0.31% to -0.43% below its base-year value. For higher values of σ, the additional income effect becomes dominant, and where $\sigma = 3.50$, the fall has been reduced to -0.30%. In short, the change in household energy use is always negative and takes a U-shaped trajectory as σ is increased.

In the case of production, the change in energy use falls monotonically, from 0.64%, where σ is 0.30 to 0.11%, where it is 3.5. But note that the change is always positive, so that in the CGE model, an improvement in labour efficiency increases industrial energy use. The positive impact primarily reflects sectoral effects that operate across these simulations. The stimulus to the economy comes primarily from exports and import substitution. Although the increase in σ generates substitution of labour for energy in production, there is an underlying increase in demand coming from the more energy-intensive traded goods.

The total energy use is the weighted sum of the domestic consumption and production use figures. Where export demand is positive, the sensitivity simulations suggest that total energy use will increase even under high substitution elasticities.

4.5. Summary of Simulation Results. The long-run system-wide impacts of the increase in labour productivity on economic activity seem unambiguously positive. GDP, investment, and household income all increase, whilst the trade and the public sector deficits fall. Moreover, these benefits apply across each of the labour market closures that we consider. This is reassuring for “economic” policy goals. (Although we do not investigate the impacts on precise measures of fuel poverty (or poverty in general), we can measure the share disposable income spent on energy. For the lowest household income quintile, where fuel poverty/poverty is highest, the proportion of their income spent on energy falls so that on that basis, fuel poverty improves.)

The analytical model outlined in Section 2 identifies a range of demand and production elasticities where an improvement in labour productivity will increase both employment and reduce energy use. However, in the simulations with the more extensive CGE model with our default elasticities, total energy use always increases, as do CO_2 emissions. This occurs across all labour market closures reported we use and under all substitution elasticities where export demand is elastic. Total energy use and emissions, however, increase by less than GDP, so that energy and emissions intensities per unit of GDP fall. But on the other hand, CO_2 emissions per worker and per head of population both rise.

5. Conclusions

The impact of general economic policies on the energy system has been comparatively neglected, particularly the effect of successful national economic policies aimed at stimulating labour productivity. Such neglect might lead to unforeseen conflicts (or complementarities) between energy and economic policy goals. This is particularly important in the current policy climate, where governments across the world are actively contemplating rebuilding their economies after the COVID-19 pandemic through enhanced productivity performance whilst at the same time seeking to meet their international obligations on climate change. The UK is a notable example, with ambitions to raise productivity performance to match that of its near neighbours, to “level-up” productivity performance across regions, and a legal target to reach net-zero by 2050.

At one level, our results provide reassurance, as improved labour productivity has a positive long-run effect on all major indicators of the United Kingdom's (UK) economic performance, including gross domestic product (GDP), consumption, and investment. Although employment typically falls in the short run as capacity adjusts over time, employment ultimately rises to above its initial level. However, there are significant accompanying impacts on key elements of the energy system.

In all versions of our model that use default parameters, both long- and short-run total domestic energy use and energy used in production increase in response to improved labour productivity. Additionally, whilst energy use per unit of GDP falls, energy use per employee and per head of population increases. Similarly, industrial territorial carbon dioxide (CO_2) emissions rise, which may pose challenges for achieving zero carbon objectives. However, it is worth noting that the trade balance improves, indicating that some UK emissions may be displacing emissions in other countries. Therefore, it would be beneficial to extend the analysis to assess these implications within a multiregional or global context.

A central aim of the current policy agenda is to stimulate labour productivity, which has been flatlining for the past decade. The present analysis suggests that the pursuit of improvements in labour productivity does not necessarily increase energy use. However, for a wide range of plausible parameter values and labour market options, increased energy use is the actual long-run outcome. Clearly, policies to increase labour productivity need to be closely coordinated with those to reduce carbon emissions within a common policy framework.

Governments must acknowledge and balance the interplay between energy and economic policies. To do this, it is paramount to establish an integrated policy framework. This framework should align economic and industrial policies with carbon reduction initiatives. Investing in green technology can also aid in striking this balance. By providing incentives for such investments, we can boost energy efficiency and ease the transition to a low-carbon economy. Furthermore, education and training initiatives can instigate behavioural changes towards energy efficiency, dovetailing productivity-boosting efforts. Strengthening regulatory frameworks is another crucial step, as these frameworks should effectively control carbon emissions whilst encouraging industries to improve energy efficiency without hindering productivity growth. Research and development should also be emphasised, as they can lead to advancements in energy-efficient technologies. Likewise, promoting innovation can encourage energy-conserving industrial practices. In essence, a strategic, holistic approach to policymaking is necessary. This approach should blend energy and economic policies, deviating from the typical "business as usual" mindset. Achieving this blend will allow policymakers to meet the dual goals of increasing productivity and reducing carbon emissions.

Appendix

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,

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

where q_0 is the industry output, e_0^P is the energy use in production, and l_0 is the labour use, all in period zero. Equation (A.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,

$$w_0 = l_0 = sq_0, \tag{A.2}$$

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

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

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

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

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

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

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 (A.3),

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

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

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

Data Availability

The SAM is available for download at 10.15129/bf6809d0-4849-4fd7-a283-916b5e765950.

Disclosure

This is an extensively revised version of a prior Discussion Paper that has not undergone the process of peer review: https://strathprints.strath.ac.uk/68568/ [38].

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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