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Prices Versus Policy: An Analysis of the Drivers of the Fossil Fuel Energy Mix

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Key Points

Understanding how the composition of a country's energy mix is formed in an environment where greater government involvement is anticipated due to climate change obligations is critical. This paper is part of a project analyzing drivers of the mix and the transition to a future energy mix where renewables will have a key role. This initial study considers the fossil fuel mix in the U.S., Germany and the U.K. by undertaking a macroeconomic analysis of the importance of prices relative to policy in shaping the mix for these economies over the last 35 years.

U.S. fossil fuel mix has been primarily driven by market forces and relative prices since the early 1980s. In Germany and the U.K., on the other hand, the mix was primarily shaped by policy until the 1990s; and by relative prices thereafter as structural changes initiated a move toward liberalizing power generation markets.

The transition from coal to gas in Germany and the U.K. increased macroeconomic volatility since the price of natural gas is more volatile than that of coal and, thus, transfered this higher volatility to economic activity.

German and U.K. policies have resulted in a 'cleaner' fuel mix, but this transition was not initiated by a climate change agenda, it was the result of pro-market policies. However, Europe is now in a new 'energy transition' era with a move to increase significantly the proportion of renewables via command policies and financial incentives – thus, moving the evolution of the energy mix away from a pure market equilibrium.

Executive Summary

This paper analyzes the drivers of the fossil fuel mix in the U.S. and compares them to those in Germany and the U.K., given the varied evolution of the fossil fuel mix and the different roles played by relative prices and policy in North America and Europe. To achieve this, a Dynamic Stochastic General Equilibrium (DSGE) model was developed.

We found that the evolution of the fossil fuel mix in the U.S. for the estimated period 1980-2014 was mostly driven by the evolution of fossil fuel prices, i.e., the prices of oil, natural gas and coal, respectively. On the contrary, Germany and the U.K. faced policy and structural changes during the 1980s and 1990s, resulting in an energy transition from coal toward natural gas. During this transition, the prices of fossil fuels played a marginal role. Following each country's transitional period, and once energy policies had stabilized, prices took over as the main drivers of the fossil fuel energy mix as is the case in the U.S.

Additionally, to assess the impact of the changes in the energy mix on the German and U.K. economies, we considered a measure of the volatility of private consumption and output for the pre- and post-reform periods. We found that the reforms toward liberalizing the energy markets brought about a transition from coal to natural gas, but at the cost of increased macroeconomic volatility.

Finally, the ‘‘energy transitions’’ in both Germany and U.K. came about due to a combination of political and structural changes. In Germany, the transition was primarily due to the reunification of the old East and West Germany and the subsequent move away from the heavily central-planned coal-fired power system. In the U.K., the transition was driven by the 1980s Thatcher government's agenda to reduce the role of the state and increase efficiency by deregulating, liberalizing and privatizing different parts of the energy industry. Both transitions, however, resulted in a deregulated market-driven energy system where the fuel mix was primarily determined by relative fuel prices – more akin to that in the U.S.

Furthermore, although this resulted in a ‘‘cleaner’’ fuel mix – as the share of gas increased at the expense of coal – neither transition was instigated by the climate change agenda and the need to reduce carbon emissions. However, Europe is now in a new ‘‘energy transition’’ era given the environmental constraints, with a move to increase significantly the proportion of renewables by introducing command and incentive policies to bring about a different energy mix to that which would ensue if left purely to the market. It will, therefore, be interesting to see the impact this policy change will have on the sector and how the energy mix evolves over the next couple of decades in Europe compared to that in U.S.

Introduction

Policymakers see fuel price volatility as a risk to their economies. Consequently, they often attempt to use policies to create an energy mix that leaves their economies less vulnerable to energy price shocks. Environmental concerns also add pressure in favor of a "cleaner" energy mix. Consequently, an established energy mix is generally the result of the interaction of fuel prices, available technologies and energy policies. In other words, the mix is determined not only by the relative costs of fuels, but also by local policies that address security, environmental, economic and social aspects of the energy system. This paper aims to explain the role of fossil fuel prices relative to energy policy in creating the primary fossil fuel mix.

Figure 1 illustrates the evolving share of fossil fuels in the U.S., Germany and the U.K. from 1980 to 2014 and shows that the energy mix in the two European countries has changed far more than in the U.S. Over this period, the share of oil in U.S. fell slightly from 46 percent to 42 percent, while gas increased from 30 percent to 34 percent and coal hardly changed. Generally, the U.S. had a relatively stable fossil fuel mix over the period 1980-2014, although there was an increase in the share of gas and a fall in the share of coal toward the end of the period (see Figure 1). This, by all accounts, was due to the development of shale gas; according to Joskow (2015), the share of shale gas in U.S. gas production increased from 7 percent in 2007 to 40 percent in 2015. In Germany, although the oil share did not change dramatically over the course of the period (from 43 percent to 45 percent), gas and coal did – from 15 percent to 25 percent and from 41 percent to 30 percent, respectively. A similar pattern emerged in the U.K., with the oil, gas and coal shares changing over the period from 42 percent to 43 percent, from 21 percent to 38 percent and from 37 percent to 17 percent, respectively. (Note the spike in U.K. coal and oil shares in 1984 was due to the coal miners' strike, which took place that year and into 1985. See, for example, BBC, 2004.)

Therefore, it is worth analyzing why the fossil fuel mix evolved so differently in the U.S. compared to Germany and the U.K. and to assess the factors behind the differences. In particular, are the differences the result of market forces and, hence, primarily driven by relative fossil fuel prices? Alternatively, are they due to the different energy policies of the countries considered in the analysis? It is also worth analyzing the impact of the changing fossil fuel mix on the economies of the two European countries. In particular, are the German and British economies more or less volatile after the energy reforms of the 1980s and 1990s?

We undertake this analysis by developing a Dynamic Stochastic General Equilibrium (DSGE) model for the U.S. and then simulating the model to assess the impact of relative prices on the fossil fuel mix over 1980-2014. We then compare these results to those from similar models for Germany and the U.K., where policy intervention is believed to have had a greater impact on primary fossil fuel demand. We compare the performance of the models to assess the importance of relative prices and policy in driving the fossil fuel mix. Additionally, we develop and analyze a measure of the volatility of private consumption and output for the pre- and post-reform periods in Germany and the U.K. to assess the impact of the reforms on these economies.

The focus of the paper is to assess the impact of international prices relative to energy policy on the fossil fuel mix, so renewable and nuclear energy are not taken into account. In the past,

Figure 1. Fossil fuel energy mix.

Source: BP (2014).

the deployment of energy from renewables and nuclear has generally been the result of government strategy pursuing objectives such as energy security, greenhouse emissions reduction, economic competitiveness, industrial development or even green jobs (see Dassiti and Carnimeo, 2012 for a discussion concerning the European Union). Moreover, there are no 'international prices' for nuclear and renewable energy; hence, it is not possible to include them in the analysis. We considered the levelized cost of electricity (LCOE) as a proxy for the international price of renewable or nuclear technology; however, this was not appropriate given that the LCOE depends on factors such as the leverage, discount rate, taxes, cost of land, administrative permissions, etc. Therefore, LCOE does not allow for a homogeneous comparison.

Although some previous research has considered the energy mix (such as Dassisti and Carnimeo, 2013 for Europe; Carraro et al., 2014 for the European power sector; Vidal-Amaro et al., 2015 for the Mexican power sector), this is, to our knowledge, the first attempt to analyze the drivers of the fossil fuel energy mix in this manner. Furthermore, the literature on analyzing the impact of fuel price shocks has focused on the impact of oil prices on economic activity (see for example, Hamilton, 1983, 2003; Kilian, 2008, 2009; De Miguel et al., 2003; Kesicki, 2010; Herrera et al., 2015).
As far as we know, this is the first attempt to analyze the impact of fossil fuel prices on the energy mix and to consider the potential impact of increased natural gas price volatility on the economy.

In summary, this paper uses a macroeconomic approach to assess the relative importance of fossil fuel prices and policy in determining the primary fossil fuel mix. This is undertaken initially for U.S. and then Germany and U.K., where a priori we expect policy to play a greater role than prices given the different energy policies in U.S. and the two European countries.

The Model and Calibration

The economies of the U.S., Germany and U.K. are each represented by a stylized DSGE model to analyze the role that fossil fuel prices play in determining the hydrocarbon energy mix in each country. The models consist of an infinitely lived representative household and two production sectors with representative firms, one producing energy services and the other producing final output. Given that the analysis aims to assess the effect of fossil fuel prices (relative to policy) on the fossil fuel mix, not the determination of prices, fossil fuel prices are assumed to be exogenous and stochastic. Details of the model can be found in Appendix A and the calibration for the three countries in Appendix B. There is a detailed description of the data in Appendix C.

Simulation Results

United States

Applying the calibrated and estimated U.S. parameters from above, the model was simulated using the software program DYNARE, which is a freely available software platform accessible from http://www.dynare.org/. In an initial step, we simulate the behavior of the hydrocarbon energy mix with actual fossil fuel price data from 1980 to 2014 as exogenous inputs to the model.

Figure 2 compares the actual fossil fuel shares for oil, natural gas and coal with the predicted shares from the model simulation. The simulated results 'predict' the actual shares relatively well, including the impact of large fossil fuel price fluctuations. For example, from 2000 the price of oil increased relative to natural gas and coal, which is reflected in the simulated results and the actual shares, both showing a sharp increase in the share of natural gas and a decline in the share of oil in the fossil fuel mix. However, the model predicts a more stable evolution of coal's share in the mix than actually occurred, suggesting that coal should represent around 26 percent of the fossil fuel mix during 1980-2014, which is not consistent with the actual data for the period. The larger share of coal consumption during those years probably reflects the response to the 1970s oil embargo, when power generation in U.S. switched from oil to coal for energy security reasons (see EIA, 2012a), rather than in response to a change in the relative price of coal. In addition, the model does not pick up the sharp decline in the share of coal since 2008, which may be due to the implementation of new energy policies. According to the IEA/IRENA (n.d.), 27 new policies on climate change entered into force in 2009 and 2010 following President Obama's electoral pledge. However, the evolution of the natural gas share is very well captured by the model, suggesting that prices mostly explain the increase in natural gas consumption since 2008 and the rise of its share in the energy mix.

In summary, the model does a good job in explaining how the U.S.'s fossil fuel mix evolved over the period 1980 to 2014, suggesting that relative fossil fuel prices generally determine the U.S.'s fossil fuel mix. The next section considers Germany and the U.K., to analyze whether such a model can explain the fossil fuel mix evolution as successfully in countries where there have been more structural change and where energy policy is more active.

Germany

The simulation for Germany is run for the whole period, but using the calibrated parameters for the period 2003-2014, as explained above. Figure 3 represents actual German energy mix for the whole period compared to that predicted by the model using the calibrated parameters for 2003-2014. The model predicts the fossil fuel mix relatively well for the 2003-2014 period, suggesting that relative fuel prices were the main driver of the fossil fuel mix during that time. In particular, the model captures the decline of the share of oil after 2008 while the shares of gas and coal were relatively stable.

The price of fossil fuels appeared to adequately predict the U.S.'s fuel mix for the whole period, suggesting that the role of policy had a minor impact compared to the relative price drivers. However, a very different situation is observed for Germany. Figure 3 illustrates the noticeable change in the German fossil fuel mix from 1990 onwards, probably driven by energy policy and the structural changes that followed German reunification.

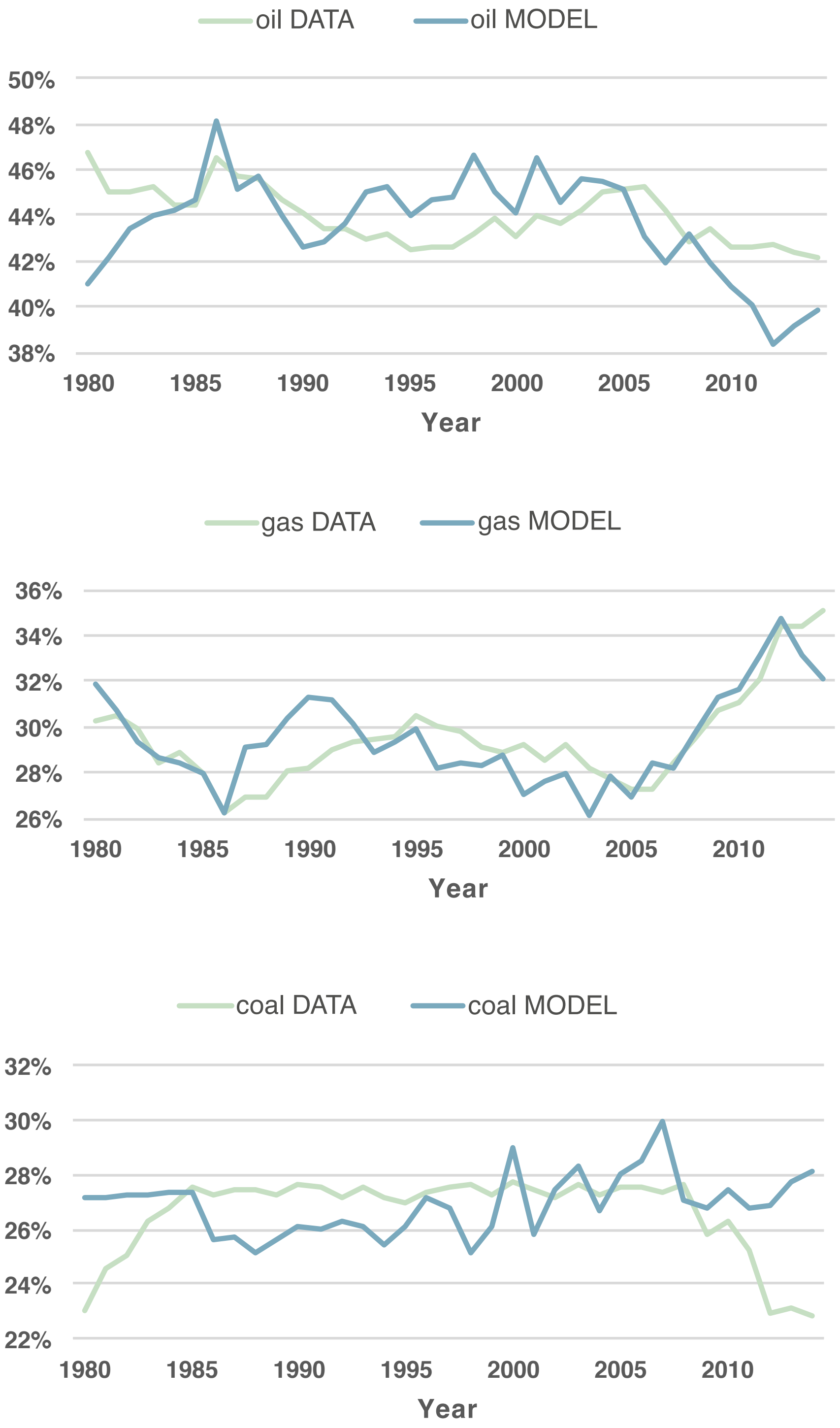


Figure 2*.* U.S. fossil fuel shares according to the actual data and the model.

Source: BP (2014) and KAPSARC.

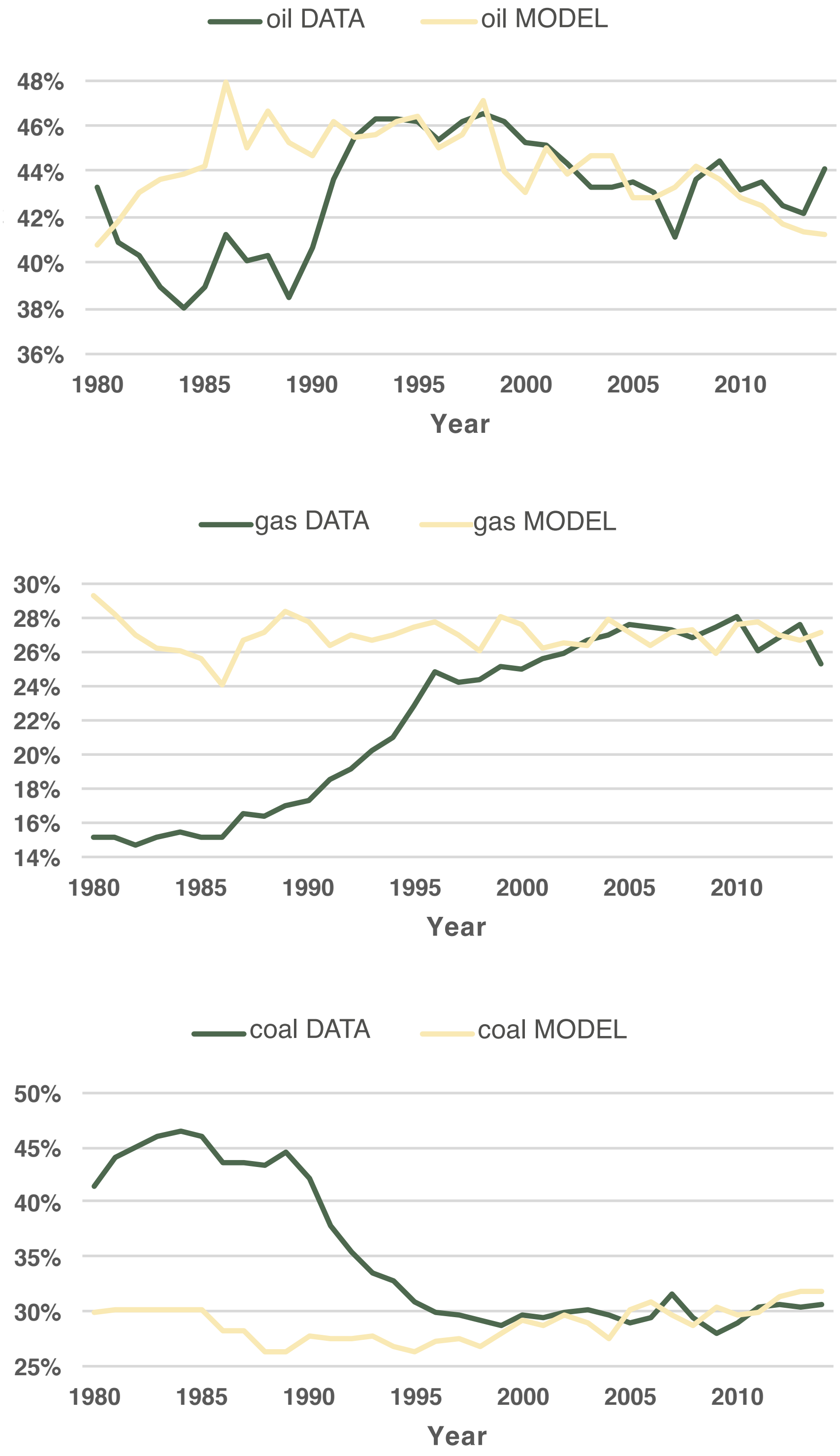


Figure 3. German fossil fuel shares according to the actual data and the model.

Source: BP (2014) and KAPSARC.

This clearly highlights that large shifts in energy policy accompanied by structural changes in energy marginalize the role of fossil fuel prices in determining the energy mix.

Given that the parameters for the German simulation model are taken from a sub-period of the data, we analyzed alternative model parametrizations. The reforms in Germany in the 1990s favored more liberalized markets, implying that fossil fuel prices should have a higher impact on the mix in the later part of the sample. In other words, given that prices drive the model, the model should adjust better in the later part of the sample. We, therefore, divided the sample into three sub-periods: 1980-1990, 1991-2002 (the transition period) and 2003-2014. For each sub-period, we calibrated the parameters of the energy services production function and ran the model to compare the actual fossil fuel mix with that predicted by the model using actual prices.

To compare the quality of the model predictions, we calculate for each sub-period the average of the sum of the quadratic difference between the shares predicted by the model and actual shares of the fossil fuel mix, i.e., the sum of quadratic prediction errors for each fuel share given by the formula $\left(\frac{\sum(Data - Model)^2}{n}\right)$. Table 1 shows that, as expected, the model predictions are most accurate for the 2003-2014 sub-period. The calibration for this sub-period produces the smallest prediction errors for oil and natural gas. For coal, the prediction errors for 2003-2014 are smaller than for the transition period and approximately equal to zero for this period and the first sub-period 1980-1990.

Table 1. Average of the sum of quadratic errors for Germany.

	Oil	Natural Gas	Coal
Calibration 2003-2014	0.0002	0.0002	0.0000
Calibration 1991-2002 (transition period)	0.0003	0.0011	0.0006
Calibration 1980-1990	0.0007	0.0004	0.0000

Source: BP, (2014) and KAPSARC.

United Kingdom

For the U.K., the model was simulated over the whole period 1980-2014 using the calibrated parameters from 1998-2014, as formerly discussed. Figure 4 shows the results for U.K. fossil fuel mix. The model predicts the share of oil reasonably well for the whole period, but markedly over-predicts the gas share and under-predicts the coal share up until the late 1990s. This result is not surprising given that the nationalized coal and electricity industries in the U.K. were restructured, liberalized and privatized, with the full effect coming through in the mid to late 1990s. Moreover, during the publicly owned period and the initial few years of the privatized era, power producers were contracted to use a certain amount of U.K. coal. Unsurprisingly, the relative fossil fuel prices in the model over-predict the gas share and under-predict the coal share during this time.

As soon as the privatized electricity sector was released from such constraints in about the mid-1990s, the situation changed and relative fuel prices clearly affected the fossil fuel shares. From about the mid-1990s, the share of coal fell and that of natural gas rose, reflecting the new CCGT stations that incumbent and new power producers built in the so-called ‘‘dash-for-gas’’ (Watson, 1997 points out that there are many factors which explain the success of this technology in the 1990s).

The model clearly predicts this. Therefore, as in Germany, the model replicates well the period that matches its calibration, i.e., when the parameters are stable. This result is consistent with the periods when market forces, and hence relative prices, shaped the fossil fuel mix.

The U.K. model should perform well after the market-oriented reforms took effect. Therefore, as in Germany, we analyze different model parametrizations by dividing the sample into three sub-periods: 1980-1990, 1991-1997 (the transition period) and 1998-2014. Again, we calibrate the parameters for the energy services production function for each sub-period to compare the actual fossil fuel mix with that predicted by the model. As with Germany, based on the sum of quadratic errors for each fuel share, the model predictions are most accurate for the final 1998-2014 sub-period. As Table 2 shows, the prediction errors for natural gas and coal are smaller in the 1998-2014 sub-period, although for oil the prediction errors are smallest during the transition period.

Table 2. Average of the sum of quadratic errors for the U.K.

	Oil	Natural Gas	Coal
Calibration 1998-2014	0.0004	0.0002	0.0004
Calibration 1991-1997 (transition period)	0.0000	0.0017	0.0016
Calibration 1980-1990	0.0013	0.0012	0.0005

Source: BP, (2014) and KAPSARC.

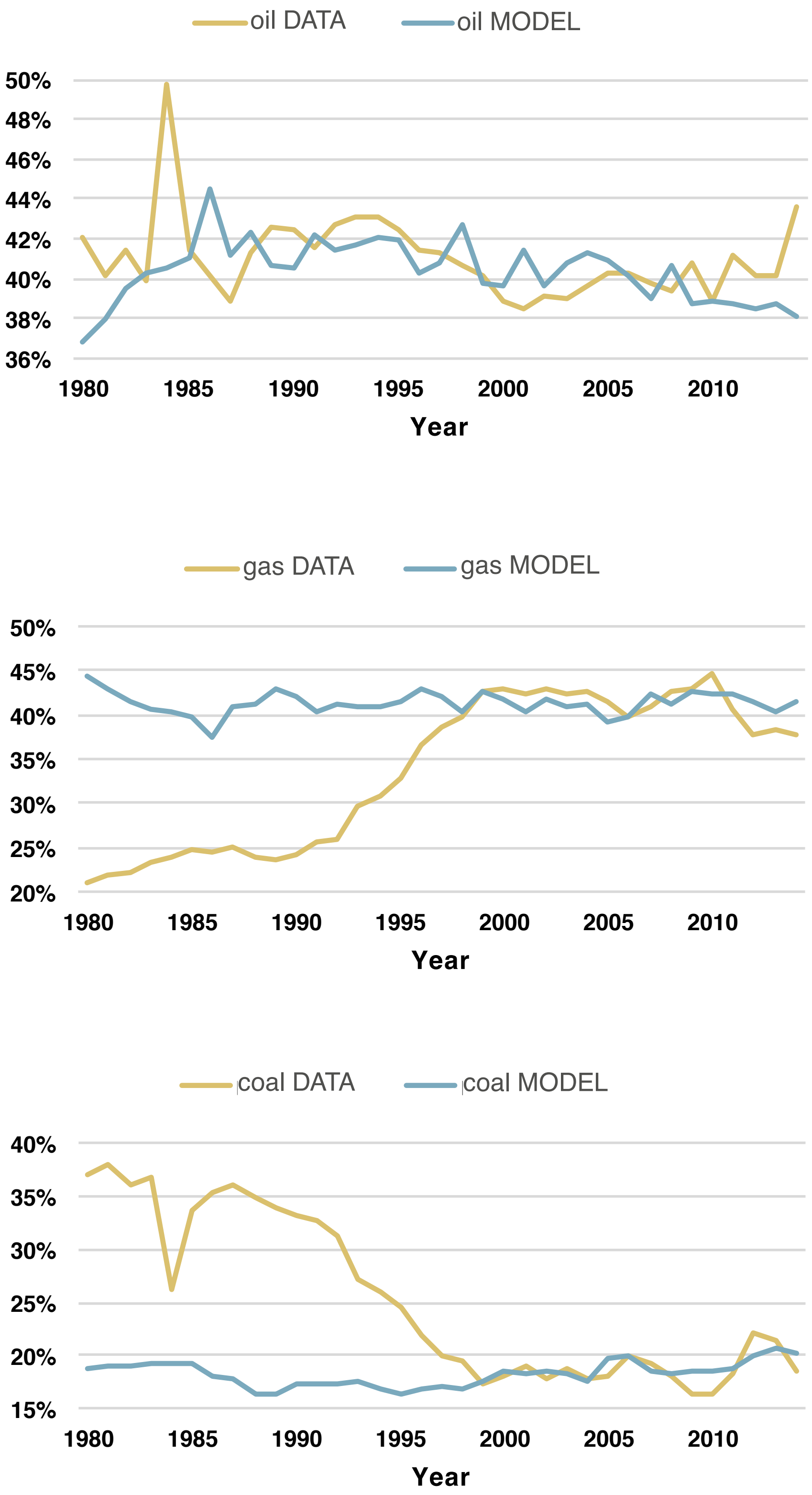


Figure 4. U.K. fossil fuel shares according to the actual data and the model.

Source: BP (2014) and KAPSARC.

The economic results of the energy reforms in Germany and U.K.

Germany and the U.K. reformed and liberalized their energy systems in the 1990s based on the premise that market-oriented economies allow for greater competition, which should improve efficiency, lower prices, increase final consumption and raise social welfare. As already highlighted, these reforms resulted in a dramatic change in the fossil fuel mix, with the share of natural gas increasing and coal decreasing while the share of oil remained more or less stable. This change potentially exposed the two economies to more volatile fossil fuel prices; in particular, more volatile natural gas compared to coal. As discussed in the introduction, policymakers perceive increased fuel price volatility as a risk (see, for example, the discussion about the volatility of oil prices on the economy in Kantchev, 2015; Klevnäs et al, 2015). Nonetheless, how changes in the fossil fuel mix affect the vulnerability of the economic system remains, to our knowledge, unexplored; therefore, we examine that question in this section.

To discover whether the shift in the fossil fuel mix created a more volatile economic environment, we calculated the volatility of private consumption and output for Germany and the U.K. for the parametrizations covering the 1980-1990 period for both countries, and 2003-2014 for Germany and 1998-2014 for the U.K. In order to do this we generate Monte Carlo simulations for fossil fuel prices and then we calculate the standard deviation of the macroeconomic variables produced by the model. The results, shown in Table 3, suggest that private consumption and output are on average 5 percent more volatile due to changes in the fossil fuel mix resulting from the reforms of the 1990s.

Table 3. Standard deviation according to the model.

Germany	Private consumption	Output
Calibration 1980-1990	0.0101	0.0196
Calibration 2003-2014	0.0107	0.0205
Percent Difference	5.9	4.6

U.K.	Private consumption	Output
Calibration 1980-1990	0.0093	0.0171
Calibration 1998-2014	0.0098	0.0179
Percent difference	5.4	4.7

Source: KAPSARC.

The prices of oil and natural gas, at least in Europe, tend to move in parallel and are strongly correlated, as shown in Table B2.3 (in Appendix B). This implies that oil price shocks are directly translated into natural gas price shocks of similar magnitude. Table 4 shows the coefficient of variation of fossil fuel prices in real terms for both European countries. Coal is the least volatile fossil fuel price. Given the higher volatility of natural gas prices relative to coal, these reforms have arguably generated a more volatile economic environment. In summary, the German and British energy transitions toward natural gas as a consequence of a move to a more market orientated approach resulted in a 'cleaner' energy mix, but at the cost of increased economic volatility.

Table 4. Coefficient of variation of real fossil fuel prices.

	Oil	Natural gas	Coal
Germany	0.53	0.46	0.30
U.K.	0.51	0.46	0.29

Source: BP (2014), EIA (n.d.) and AMECO (n.d.).

Conclusions and Policy Interpretations

The U.S. is one of the world's most market-driven economies. On the other hand, the two European comparator countries, Germany and the U.K., have undergone significant structural and energy policy changes since the 1980s. The U.S. has experienced a relatively stable fossil fuel mix since 1980, while in Germany and the U.K., the share of natural gas increased dramatically at the expense of coal. If market forces dominated, then the observed change in the fossil fuel mix in Germany and the U.K. would be consistent with an increase in the relative price of coal compared to natural gas. However, historical fossil fuel prices did not follow this trend, suggesting that energy policy played an important role in the evolution of the fossil fuel mix in Germany and the U.K.

This paper analyzes the drivers of the fossil fuel mix in the U.S. and compares them to Germany and the U.K., given the different evolution of the fossil fuel mix and the different roles that price and policy have played in North America and Europe. To achieve this, we developed a DSGE model for the U.S. and then simulated the impact of relative prices on the fuel mix over the period 1980-2014. We then compared the results from similar DSGE models for Germany and the U.K. In addition, we considered a measure of the volatility of private consumption and output for the pre- and post-reform periods for Germany and the U.K. to assess how changes in the fossil fuel mix affected these two economies.

For the U.S., we found that the calibrated DSGE model explains well the evolution of the U.S.'s fossil fuel mix over the whole of 1980 to 2014, suggesting that relative fossil fuel prices and the market generally dominated the determination of the U.S. fossil fuel mix over the period. However, a different picture emerges for Germany and the U.K., where dramatically changing shares of natural gas and coal cannot be explained by a DSGE model calibrated over the whole period. Instead, the model for Germany is calibrated using data from 2003-2014 and the U.K. model using data for 1998-2014. For both Germany and the U.K., the models perform well following the countries' transitional periods, when the allocation of resources in the energy sector became more market-oriented.

Furthermore, given the dramatic increase in the shares of natural gas in Germany and the U.K., we considered the potential impact on the two economies by analyzing the potential for increased volatility in private consumption and output. This analysis shows that, given the greater volatility of natural gas prices compared to coal, the move toward gas has generated a more volatile economic environment in both Germany and the U.K. The German and British energy transitions toward natural gas have resulted in a 'cleaner' energy mix, but at the cost of increased economic volatility.

The analysis in this paper not only sheds light on the drivers of the fossil fuel mix, but also shows that the impact of natural gas price shocks on the fossil fuel mix could potentially be as important as previous oil price shocks. These issues, as far as we know, have not been addressed empirically in the literature, where the focus has been the impact of oil price shocks on economic activity.

Finally, the past 'energy transitions' in both Germany and the U.K. that were considered in this paper came about due to a combination of political and structural changes. In Germany, the transition was primarily from the reunification of the old East and West Germany and the subsequent move away from the heavily central-planned coal-fired power system. In the U.K., the transition was driven by the 1980s Thatcher government's agenda to reduce the role of the state and increase efficiency by deregulating, liberalizing and privatizing the different parts of the energy industry. Both transitions, however, resulted in deregulated market-driven energy systems where the fuel mix was shaped primarily by market determined relative fuel prices – more akin to that in the U.S.

Even though this resulted in a 'cleaner' fuel mix – as the share of gas increased at the expense of the share of replaced coal – neither transition was instigated by the environmental agenda and the need to reduce carbon emissions. However, Europe is now in a new 'energy transition' era given the environmental constraint, with a move to increase significantly the proportion of renewables by introducing command and incentive policies to bring about a different energy mix to that that would ensue if left purely to the market. It will therefore be interesting to see the impact this has and how the energy mix evolves over the next couple of decades in Europe compared to that in the U.S.

References

AMECO, n.d. Annual macro-economic database. European Commission's Directorate General for Economic and Financial Affairs, http://ec.europa.eu/economy_finance/db_indicators/ameco/index_en.htm, (Accessed Aug. 28, 2015).

BBC, 2004. The Miners' Strike Revisited. British Broadcasting Company, Inside Out East Midlands, Monday Feb. 2, http://www.bbc.co.uk/insideout/eastmidlands/series5/miners_strike_coal.shtml, (Accessed April 20, 2016).

BP, 2014. BP Statistical Review of World Energy, 63rd Edition. http://www.bp.com/content/dam/bp-country/de_de/PDFs/brochures/BP-statistical-review-of-world-energy-2014-full-report.pdf, (Accessed April 20, 2016).

Burniaux, J-M., Truong T. P., 2002. GTAP-E: an energy-environmental version of the GTAP model. GTAP Technical Papers: 18.

Carraro, C., Tavoni, M. Longden, T., Marangoni, D., 2014. The Optimal Energy Mix in Power Generation and the Contribution from Natural Gas in Reducing Carbon Emissions to 2030 and Beyond. The Harvard Project on Climate Agreements, Discussion Paper 14-63, January.

Dassisti, M., Carnimeo, L. 2012. Net modelling of energy mix among European Countries: A proposal for ruling new scenarios. Energy, 39(1), 100-111.

De Miguel, C., Manzano, B., Martin-Moreno, J. M. 2003. Oil price shocks and aggregate fluctuations. The Energy Journal, 47-61.

De Miguel, C. and Manzano, B., 2006. Optimal oil taxation in a small open economy. Review of Economic Dynamics, 9(3), 438-454.

EIA, 2012a. Petroleum Chronology of Events 1970 – 2000. US Energy Information Administration, Independent Statistics & Analysis, Petroleum & Other Liquids, May, http://www.eia.gov/pub/oil_gas/petroleum/analysis_publications/chronology/petroleumchronology2000.htm, (Accessed April 20, 2016).

EIA, 2012b Fuel competition in power generation and elasticities of substitution. US Energy Information Administration, Independent Statistics & Analysis, Analysis & Projections, June, https://www.eia.gov/analysis/studies/fuelelasticities/pdf/eia-fuelelasticities.pdf, (Accessed April 20, 2016).

EIA, n.d. Natural Gas Annual Database. US Energy Information Administration, http://www.eia.gov/naturalgas/data.cfm, (Accessed Aug. 28, 2016).

Golosov, M., Hassler, J., Krusell, P. Tsyvinski, 2014. A. Optimal taxes on fossil fuel in general equilibrium. Econometrica, 82(1), 41-88.

Green, R., 1991. Reshaping the CEGB: Electricity Privatization in the U.K. Utilities Policy, 1(3), 245-254.

Green, W. H., 2012. Econometric Analysis (7th Ed). Prentice Hall.

Hamilton, J. D., 1983. Oil and the macroeconomy since World War II. Journal of Political Economy, 91(2), 228-248.

Hamilton, J. D., 2003. What is an oil shock? Journal of Econometrics, 113(2), 363-398.

Havranek, T., Horvath, R., Irsova, Z., Rusnak. M., 2015. Cross-country heterogeneity in intertemporal substitution. Journal of International Economics, 96(1), 100-118.

Herrera, A. M., Lagalo, L. G., Wada, T., 2015. Asymmetries in the response of economic activity to oil price increases and decreases? Journal of International Money and Finance 50, 108-133.

References

IEA/IRENA n.d. Joint Policies and Measures Database for Global Renewable Energy. International Energy Agency, OECD, https://www.iea.org/topics/renewables/renewablesiea/policiesmeasuresdatabasepams/, (Accessed April 20, 2016).

Joskow, P. L., 2015. The Shale gas revolution: introduction. Economics of Energy & Environmental Policy, 4(1), 1-4.

Kantchev, G., 2015. Volatile Oil Market May Hurt Global Economy. The Wall Street Journal, May, http://www.wsj.com/articles/volatile-oil-market-may-hurt-global-economy-1431424383, (Accessed April 20, 2016).

Kesicki, F., 2010. The third oil price surge–What's different this time? Energy Policy, 38(3), 1596-1606.

Kilian, L. 2008. The economic effects of energy price shocks. Journal of Economic Literature, 46(4), 871-909.

Kilian, L. 2009. Not all oil price shocks are alike: disentangling demand and supply shocks in the crude oil market. American Economic Review, 99(3), 1053-69.

Kim, I-M., Loungani. P. 1992. The role of energy in real business cycle models. Journal of Monetary Economics, 29(2), 173-189.

Klevnäs, P., Stern, N., Frejova, J. 2015. Oil Prices and the New Climate Economy, The New Climate Economy, The Global Commission on the Economy and Climate, May, http://www.ourenergypolicy.org/wp-content/uploads/2015/05/Oil-prices-and-the-New-Climate-Economy.pdf, (Accessed April 20, 2016).

Lauber, V., Mez, L., 2004. Three decades of renewable electricity policies in Germany. Energy & Environment, 15(4), 599-623.

Mănescu, C. B., Nuño, G., 2015. Quantitative effects of the shale oil revolution. Energy Policy, 86, 855-866.

Nakov, A., Nuño, G., 2013. Saudi Arabia and the oil market. The Economic Journal, 123(573), 1333-1362.

Prescott, E. C., 1986. Theory ahead of business-cycle measurement. In Carnegie-Rochester Conference Series on Public Policy, 25, 11-44. North-Holland.

Rotemberg, J., Woodford, M., 1996. Imperfect Competition and the Effects of Energy Price Increases on Economic Activity. Journal of Money, Credit and Banking, 28(4), Part 1, 549-577.

Stern, J. P., 2009. Continental European Long-Term Gas Contracts: is a transition away from oil product-linked pricing inevitable and imminent? Oxford Institute for Energy Studies.

Vidal-Amaro, J. J., Østergaard, P. A., Sheinbaum-Pardo, C., 2015. Optimal energy mix for transitioning from fossil fuels to renewable energy sources – The case of the Mexican electricity system, Applied Energy, 150, 80–96.

Watson, J., 1997. The technology that drove the ‘dash for gas. Power Engineering Journal, 11(1), 11-19.

Appendix A: Description of the Model

In this study, we use a standard DSGE to understand the role of prices and policies in the energy mix. The use of calibrated dynamic, either stochastic or deterministic, general equilibrium models is not new since they have been at the core of macroeconomic analysis for the last few decades. Moreover, regarding energy, these models have mainly been used to analyze the macroeconomic effects of energy price shocks, particularly oil shocks (such as, Kim and Loungani, 1992; Rotemberg and Woodford, 1996). More recently, DSGE models have been used to analyze optimal energy taxation (De Miguel and Manzano, 2006; Golosov et al., 2014), the behavior of the oil market (Nakov and Nuño, 2013) and macroeconomic impact of the shale oil revolution (Mănescu and Nuño, 2015). However, in this paper, we use a DSGE model for a different purpose. We analyze the effects of fossil fuel prices compared to energy policies in explaining changes in the fossil fuel mix. Furthermore, we consider the impact of the changing mix on the economic volatility of the two European countries.

A1. The representative household

The representative household's preferences are characterized by a utility function:

$$U(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}, \tag{1}$$

where c_t is consumption at time t and σ is the inverse of the intertemporal elasticity of substitution of consumption. The household maximizes an intertemporal expected discounted flow of utility subject to the budget constraint and capital accumulation:

$$\max_{c_t, K_{t+1}} E_0 \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\sigma}}{1-\sigma}$$

subject to:

$$c_t + k_{t+1} - (1-\mu)k_t = w_t n_t + r_t k_t\ ,$$

where. the variable k_t is capital, r_t is the interest rate, w_t are wages and n_t is the quantity of labor, all at time t. The parameter β is the discount factor and μ is the capital depreciation rate. The first order conditions that define optimal household behavior are:

$$\frac{\partial U}{\partial c_t} = \beta E_t \frac{\partial U}{\partial c_{t+1}} (1 - \mu + r_{t+1}), \tag{2}$$

$$c_t + k_{t+1} - (1-\delta)k_t = w_t n_t + r_t k_t. \tag{3}$$

Eq. (2) is the Euler condition that governs the intertemporal substitution of consumption and Eq. (3) represents the budget constraint. In addition, the transversality condition for capital is:

$$\lim_{t\to\infty} \frac{\partial U}{\partial c_t} k_t = 0. \tag{4}$$

A2. Representative firms

Two different sectors are considered, one producing 'energy services' and the other producing 'final goods and services.' Each sector is represented by a profit maximizing firm.

The final goods and services firm

The firm producing final goods uses labor, capital and energy services as inputs according to a constant returns to scale Cobb-Douglas production function:

$$Y_t = n_t^{\alpha} k_t^{\phi} E_{S_t}^{1-\alpha-\phi}, \qquad (5)$$

where Y_t is final output and Es_t is the output of energy services, both at time *t*. The first order conditions for the final goods firm to maximize profits are:

$$w_t = \alpha n_t^{\alpha-1} k_t^{\phi} E_{S_t}^{1-\alpha-\phi}, \qquad (6)$$

$$r_t = \phi n_t^{\alpha} k_t^{\phi-1} E_{S_t}^{1-\alpha-\phi}, \qquad (7)$$

$$P_{S_t} = (1-\alpha-\phi) n_t^{\alpha} k_t^{\phi} E_{S_t}^{-\alpha-\phi}, \qquad (8)$$

where Ps_t is the price of energy services at time *t* and the price of the aggregate good is normalized to one, so that all prices in the economy are real prices. The quantity of labor is also normalized to one to simplify the analysis. Equations (6) to (8) imply that input prices are equal to the respective marginal productivities. From these, the parameters α (the share of labor income in output), *ø* (the share of capital income in output) and 1-α-*ø* (the share of energy services expenditure in output) can be derived.

The energy services firm

The representative firm in the energy sector produces energy services by combining fossil fuels through a constant elasticity of substitution (CES) production function with constant returns to scale. A CES production function is preferred to a Cobb-Douglas production function for energy services, given that the interfuel elasticity of substitution is somewhat different from one (which is explained and discussed in the calibration section below). Thus, the chosen specification of technology is similar to that used in Golosov et al. (2014), but with a different combination of energy sources:

$$E_{S_t} = \left[aE_{O_t}^{\delta} + bE_{G_t}^{\delta} + cE_{C_t}^{\delta}\right]^{1/\delta} \qquad (9)$$

where EO_t, EG_t and EC_t are the quantities of oil, natural gas and coal in time t, respectively. The parameter δ governs the interfuel elasticity of substitution amongst the fossil fuel inputs.

The profit maximizing first order conditions for the energy services firm are:

$$\frac{P_{Oil_t}}{P_{S_t}} = aE_{O_t}^{\delta-1}\left[aE_{O_t}^{\delta} + bE_{G_t}^{\delta} + cE_{C_t}^{\delta}\right]^{\frac{1-\delta}{\delta}}, \qquad (10)$$

$$\frac{P_{Gas_t}}{P_{S_t}} = bE_{G_t}^{\delta-1}\left[aE_{O_t}^{\delta} + bE_{G_t}^{\delta} + cE_{C_t}^{\delta}\right]^{\frac{1-\delta}{\delta}}, \qquad (11)$$

$$\frac{P_{Coal_t}}{P_{S_t}} = cE_{O_t}^{\delta-1}\left[aE_{O_t}^{\delta} + bE_{G_t}^{\delta} + cE_{C_t}^{\delta}\right]^{\frac{1-\delta}{\delta}}, \qquad (12)$$

where P_{oil_t} , P_{Gas_t} and P_{Coal_t} are the prices of oil, gas and coal, respectively, in time t. Eqs. (10) to (12) show that profit maximization by the energy services firm requires the relative prices of fossil fuels to equal their marginal productivities. Reorganizing these, the following equations for parameters a, b and c are obtained:

$$a = \frac{P_{Oil_t}E_{O_t}^{1-\delta}}{P_{Oil_t}E_{O_t}^{1-\delta} + P_{Gas_t}E_{G_t}^{1-\delta} + P_{Coal_t}E_{C_t}^{1-\delta}} \qquad (13)$$

$$b = \frac{P_{Gas_t}E_{G_t}^{1-\delta}}{P_{Oil_t}E_{O_t}^{1-\delta} + P_{Gas_t}E_{G_t}^{1-\delta} + P_{Coal_t}E_{C_t}^{1-\delta}} \qquad (14)$$

$$c = \frac{P_{Coal_t}E_{C}^{1-\delta}}{P_{Oil_t}E_{O_t}^{1-\delta} + P_{Gas_t}E_{G_t}^{1-\delta} + P_{Coal_t}E_{C_t}^{1-\delta}} \qquad (15)$$

where a is the distribution parameter for oil, b is the distribution parameter for natural gas and *c (=1-a-b)* is the distribution parameter for coal.

A3. Prices of fossil fuels

Fossil fuel prices are assumed to be exogenous and follow stochastic processes:

$$\ln P_{Oil_t} = (1-\rho_O)\ln P_{Oil}^{ss} + \rho_O \ln P_{Oil_{t-1}} + \varepsilon_t^O,$$

$$\ln P_{Gas_t} = (1-\rho_G)\ln P_{Gas}^{ss} + \rho_G \ln P_{Gga_{t-1}} + \varepsilon_t^G,$$

$$\ln P_{Coal_t} = (1-\rho_C)\ln P_{Coal}^{ss} + \rho_C \ln P_{Coal_{t-1}} + \varepsilon_t^C,$$

where P^{ss}_{oil}, P^{ss}_{gas} and P^{ss}_{coal} represent the steady state values around which each price fluctuates. The variables ε^{0}_{t}, ε^{G}_{t} and ε^{C}_{t} represent innovations in the stochastic processes. These variables are assumed to follow a normal multivariate process:

$$\begin{bmatrix} \varepsilon_t^O \\ \varepsilon_t^G \\ \varepsilon_t^C \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_O^2 & & \\ \sigma_{OG} & \sigma_G^2 & \\ \sigma_{OC} & \sigma_{GC} & \sigma_C^2 \end{bmatrix} \right)$$

A4. The competitive equilibrium

The competitive equilibrium for this economy is a set of allocation and price paths that satisfy the following conditions:

- $\{c_t, k_t\}$ solve the household's problem given prices $\{r_t, w_t\}$.
- $\{EO_t, EG_t, Ec_t\}$ maximize the profits of the energy services firm given fossil fuel prices $\{P_{Oil_t}, P_{Gas_t}, P_{Coal_t}\}$.
- $\{n_t, k_t, Es_t\}$ maximize the profits of the firm that produces the aggregate good given input prices $\{w_t, r_t, Ps_t\}$.
- All the markets clear.

In summary, the theoretical model above is characterized by:

- A representative household with rational expectations that maximizes consumption over time.
- An energy services firm with a constant elasticity of substitution production technology that maximizes profits in a competitive environment.
- A final goods and services firm with Cobb Douglas technology of production that maximizes profits in a competitive environment.
- Exogenous stochastic fossil fuel prices.

This theoretical model is nonlinear and stochastic; hence, it is not possible to obtain analytical solutions. Therefore, the model is solved numerically and numerical values for the parameters are required. The following sections describe the calibration and econometric estimation for the U.S., Germany and the U.K.

Appendix B: Model Calibration

B1: U.S.

B1.1: Energy services firm

The interfuel elasticity of substitution measures how fuel consumption varies as relative fuel prices change. As mentioned in the previous section, this parameter is not necessarily close to one. We assume that δ=-3, which implies that the interfuel elasticity of substitution is 0.25, similar to that suggested by Burniaux and Truong (2002). In the same context, the EIA (2012b) finds relatively low cross price elasticities for most technologies (note the average of the estimated cross price elasticities of substitution is 0.28).

For a given value of δ and actual data for the period 1980-2014, Eqs. (13) to (15) allow the calibration of parameters *a, b* and c. (See the Annex for a detailed description of the data). The calibrated parameters for the U.S. are shown in Figure. B1.1 and the averages for different sub-periods in Table B1.1. (Note the range of the vertical axes for the U.S. charts are the same as those presented below for Germany and the U.K. to aid comparison). Figure. B1.1 and Table B1.1 show that the three calibrated parameters are relatively stable for U.S. over the whole period, with no discernable difference in the parameters across time. Moreover, as shown in Table B1.1, the coefficients of variation for *a, b* and *c* are 4 percent, 27 percent and 38 percent respectively. In other words, the variation in *a* is relatively small, whereas it is slightly larger for *b* and *c.* However, these are still regarded as relatively stable and so, for the U.S., the average calibrated parameters *a*, *b* and *c* from the whole sample (1980 to 2014) are used when running the simulations discussed below.

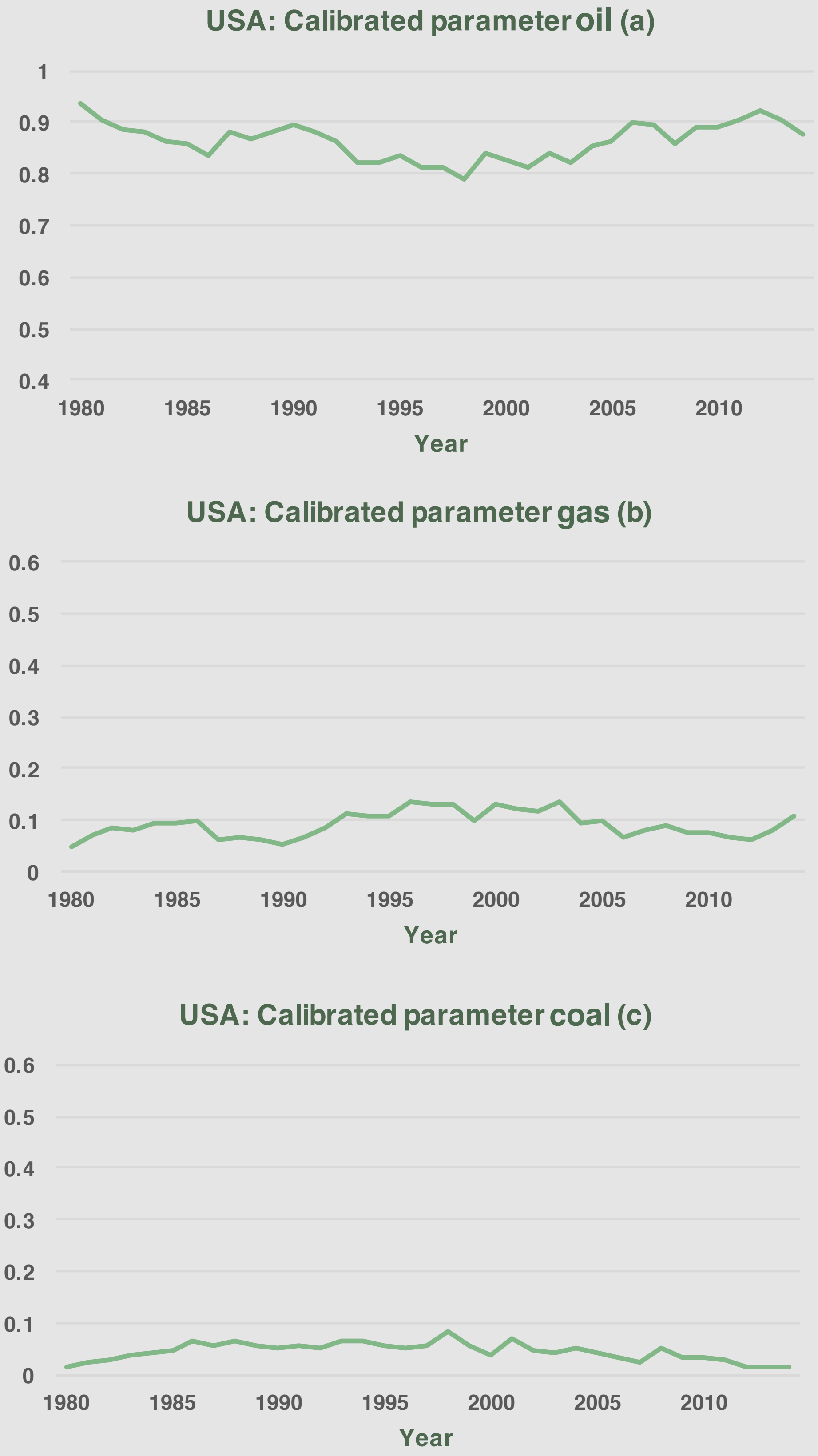


Figure B1.1. U.S. calibrated energy services production function parameters.

Source: KAPSARC.

Table B1.1. U.S. calibrated energy services production function parameters.

Period	a	b	c
1980-1990	0.88	0.08	0.04
1991-2000	0.83	0.11	0.06
2001-2010	0.86	0.10	0.04
2011-2014	0.90	0.08	0.02
Mean	0.86	0.09	0.04
Standard deviation	0.04	0.02	0.02
Coefficient of variation	0.04	0.27	0.37

Source:KAPSARC.

B1.2: Final goods firm

Table B1.2 gives the U.S. calibrated parameters for the final goods firm, α, $\emptyset$ and $1-\alpha-\emptyset$ over the whole period, derived from Eqs. (6) to (8).

Table B1.2. U.S. calibrated final goods production function.

Period	α	$\emptyset$	$1-\alpha-\emptyset$
1980-2014	0.60	0.34	0.06

Source: KAPSARC.

B1.3 The household

Following the meta-analysis of Havranek et al. (2015), we assume an intertemporal elasticity of substitution equal to 0.5, implying б= 2. Using standard values from the macroeconomic literature (see for example, Prescott, 1986), the parameter β is assumed to equal 0.96 and μ is assumed to equal 0.1.

B1.4 Fossil fuel prices

Table B1.3 presents the correlation coefficients between the real prices of crude oil, coal and natural gas. The price of coal is relatively strongly correlated with the price of oil, but the correlation of the price of natural gas with both oil and coal is less strong. This is consistent with the view that in the U.S., natural gas prices 'decoupled' from oil prices following the emergence of shale gas (see Joskow, 2015), given that for the period 1980-2006 the correlation between the oil price and natural gas was 0.63 compared to 0.40 over the whole period.

Given the strong correlations between prices, it would be wrong to assume that the residuals of the stochastic processes given in Eqs. (16) to (18) are independent. On the contrary, the high correlations suggest that energy prices are affected by the same shocks. We therefore model prices using a seemingly unrelated regression (SUR) method, allowing the shocks on the three fossil fuel prices to be contemporaneously correlated (see Green, 2012). Table B1.4 presents a summary of the estimation results. Furthermore, Table B1.5 shows the covariance matrix of the residuals from the estimated equations, which imply that oil shocks, natural gas shocks and coal shocks are not independent in the model.

Table B1.3. Matrix of correlations for U.S. real prices of fossil fuels 1980-2014.

	Oil	**Natural Gas**	**Coal**
Oil	1	0.40	0.80
Natural Gas		1	0.59
Coal			1

Source: BP, (2014), EIA, (n.d.) and AMECO, (n.d.).

Table B1.4. Seemingly unrelated regression (SUR) for price models.

	Coefficient	Std. error
ρ_O (price of oil)	0.86	0.07
ρ_G (price of natural gas)	0.71	0.10
ρ_C (price of coal)	0.68	0.12

Source: KAPSARC.

Table B1.5. Covariance matrix for the errors.

	ε^O_t	ε^G_t	ε^C_t
ε^O_t	0.05	0.02	0.02
ε^G_t		0.07	0.02
ε^C_t			0.04

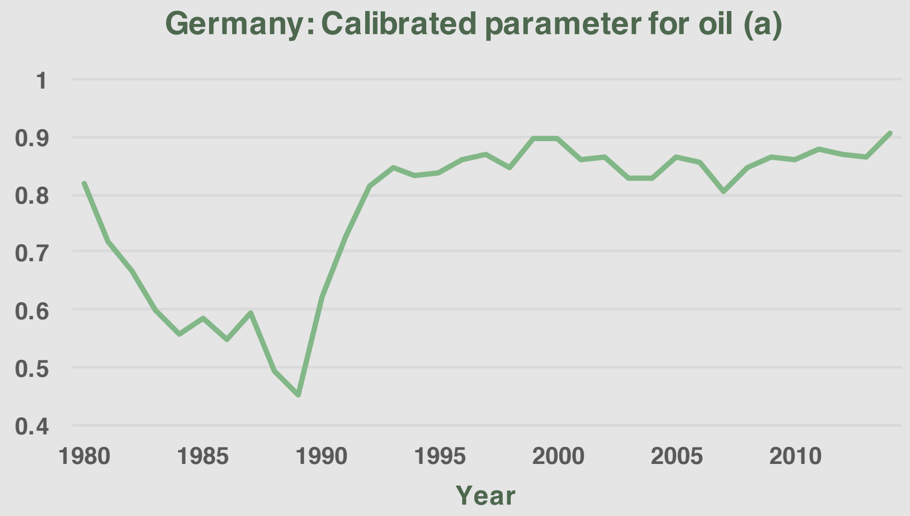
Source: KAPSARC.

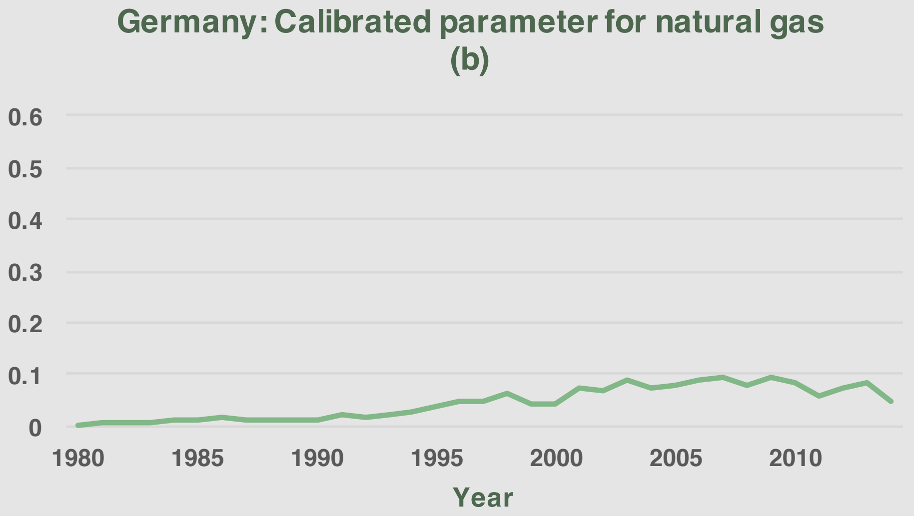
B2. Germany and U.K.

B2.1: Energy services firm

The calibrated parameters a, b and c for Germany and the U.K., using Eqs. (13) to (15) over the period 1980 to 2014, are illustrated in Figures B2.1 and B2.2, respectively. The results for different sub-periods and some summary statistics are given in Table B2.1. The calibrated parameters for Germany and the U.K. show much greater variation than those for the U.S. The coefficients of variation for a are 17 percent for Germany and 11 percent for the U.K., both higher than the 4 percent value for the U.S. This is also the case for b, with coefficients of variation of 69 percent for Germany and 71 percent for the U.K. compared to 27 percent for the U.S., as well as for *c*, with coefficients of variation of 86 percent for Germany and 44 percent for the U.K. compared to 38 percent for the U.S. These variations, highlighted by differences across the sub-periods, likely reflect the change in energy structure that accompanied German reunification in 1990 and the liberalization of the U.K. energy sector during the 1980s and the 1990s. In other words, structural change and policy factors appear to dominate the impact of changing relative prices.

Possible reasons for the greater variability in the German and U.K. calibrated parameters *a*, *b* and *c,* than the U.S., are interesting to consider. For Germany, *b* was very close to zero during the 1980s, reflecting the relatively low consumption of natural gas and oil and the importance of coal in the fossil fuel mix, likely the outcome of policies implemented by both East and West Germany during that period. In comparison, *c* averaged 0.38 during the 1980s, quite high compared to both the U.S. and the U.K. In 1991, following German reunification, energy policy changed dramatically as the eastern part of the country shifted toward a market-oriented system.


Germany: Calibrated parameter for oil (a)


Germany: Calibrated parameter for natural gas (b)

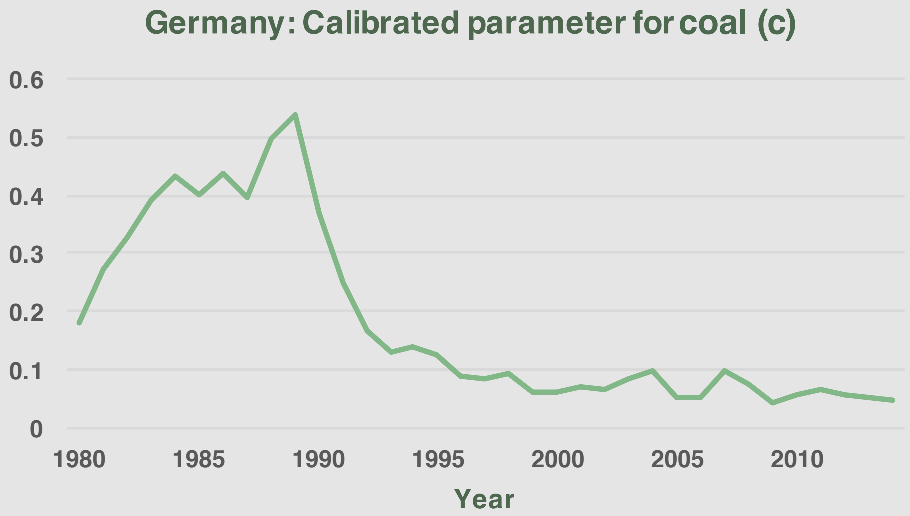

Germany: Calibrated parameter for coal (c)

Figure B2.1. Germany calibrated energy services production function parameters.

Source: KAPSARC.

For the U.K., in the 1980s the parameter c was larger and b smaller than for the remainder of the period, likely because the (then publically owned) U.K. electricity industry had to buy and use coal produced by the U.K.'s publically owned company. However, both b and c changed markedly from the early 1990s following the U.K. government's liberalization and privatization policies, when both the electricity and coal industries were restructured and sold to the private sector and the subsequent shift from coal- to gas-fired power production. (See Green, 1991 for an explanation and a discussion about the impact of privatization on the structure of the U.K. electricity market).

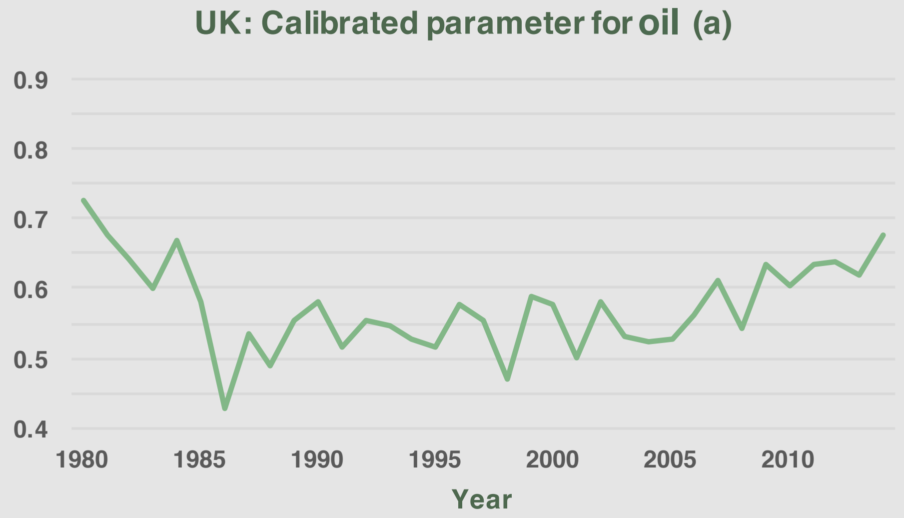
In Germany, 1991-2002 was a period of transition. Coal progressively lost market share relative to crude oil and natural gas. This transition might have been explained by a systematic increase of coal prices relative to natural gas; however, the actual path of relative prices was the opposite. For the U.K., 1991-1998 was a period of transition, and as in Germany's transition period, the evolution of relative fossil fuel prices was not consistent with the increase in natural gas consumption. Thus, for these two representative European countries, changes in the relative prices of natural gas, coal or oil cannot explain the transition from coal to natural gas. Lauber and Mez (2004) suggest that in Germany a change in energy policy toward a more clean and sustainable energy mix drove the transition toward natural gas. In U.K., an institutional change drove the transition, as the electricity system moved from a state – controlled and effectively vertically integrated system to an unbundled, privatized, liberalized and deregulated market system (as discussed in Green, 1991).

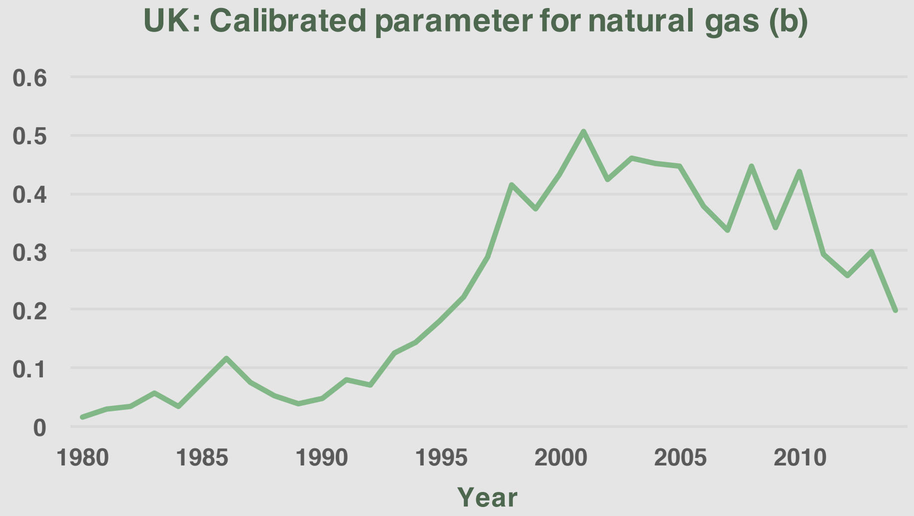
Given this variability, when simulating the model for Germany, the values for a, b and c are the averages for 2003 to 2014, since they are relatively stable over this period. For U.K., the model is calibrated using data for 1998 to 2014, given that a, b and c are relatively stable through this period. The averages for these periods for a, b and c for both countries are given in Table B2.2.

Table B2.1. Germany and U.K. calibrated energy services production function parameters.

	Germany			**U.K.**		
Period	**a**	**b**	**c**	**a**	**b**	**c**
1980-1990	0.61	0.01	0.38	0.78	0.05	0.17
1991-2000	0.85	0.04	0.12	0.71	0.23	0.06
2001-2010	0.85	0.08	0.07	0.57	0.52	0.01
2011-2014	0.88	0.07	0.05	0.73	0.26	0.01
Mean	0.77	0.05	0.18	0.57	0.23	0.15
Standard deviation	0.13	0.03	0.16	0.06	0.17	0.07
Coefficient of variation	0.17	0.69	0.86	0.11	0.71	0.44

Source: KAPSARC.





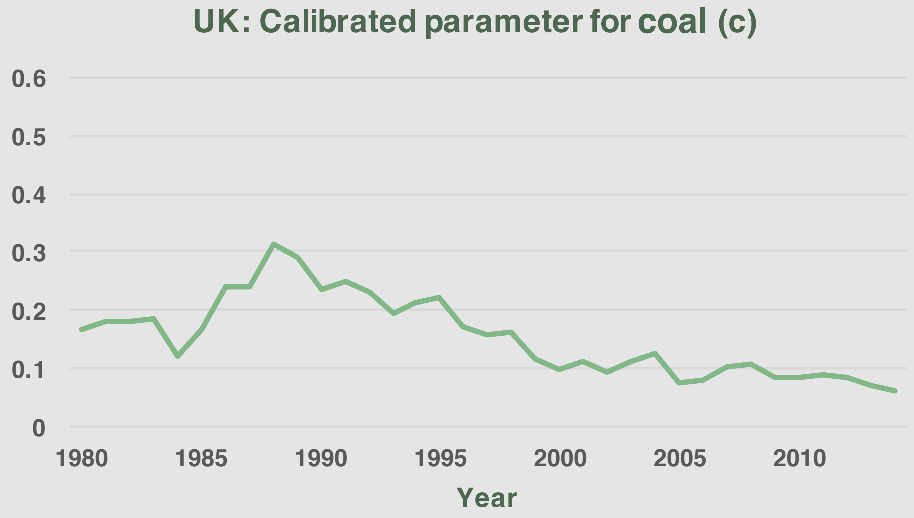


Figure B2.2. U.K. calibrated energy services production function parameters.

Source: KAPSARC.

B2.2: Final goods and services firm

Using the sub-periods identified the previous page, Table B2.2 also reports the calibrated parameters α, ø and 1-α-ø for both Germany and the U.K., derived from Eqs. (6) to (8).

B2.3: Household

The parametrization of the households for Germany and the U.K. are identical as the one used for the U.S.

B2.4: Fossil Fuel Prices

Table B2.3 presents the correlation coefficients between the real prices of crude oil, natural gas and coal for Germany and the U.K. The correlation between the price of oil and the price of natural gas for both Germany and the U.K. is much higher than that for the U.S. No 'shale gas revolution' has occurred in Europe, the main reason behind the decoupling of prices in the U.S. In addition, the high correlation could be caused by long-term natural gas contracts in Europe that are linked to oil prices, as Stern (2009) points out. Similarly, the correlation coefficient between the price of natural gas and the price of coal is about 0.8 for both Germany and the U.K. compared to about 0.6 for the U.S. Unlike in the U.S., natural gas prices in Germany and the U.K. do not appear to have 'decoupled' from oil prices. Nonetheless, as in the U.S., there is relatively strong correlation between the fossil fuel prices in Germany and in the U.K., suggesting that the prices are affected by the same shocks. Therefore, models for the fossil fuel prices in Germany and the U.K. are also estimated using the seemingly unrelated regression (SUR) method. Table B2.4 presents the main estimation results for both European countries.

Table B2.2. Calibrated parameters both production.

	Period	α	ø	1-α-ø	a	b	c
Germany	2003-2014	0.63	0.35	0.02	0.86	0.08	0.06
U.K.	1998-2014	0.65	0.32	0.03	0.57	0.42	0.01

Source: KAPSARC.

Table B2.3. Matrix of correlations for Germany and the U.K. real prices of fossil fuels 1980-2014.

	Germany			U.K.		
	Oil	**Natural gas**	**Coal**	**Oil**	**Natural gas**	**Coal**
Oil	1	0.87	0.80	1	0.85	0.76
Natural gas		1	0.83		1	0.78
Coal			1			1

Source: BP (2014), EIA (n.d.) and AMECO (n.d.).

Table B2.4. Seemingly unrelated regression (SUR) for price models.

	Germany		U.K.	
	Coefficient	**Std. error**	**Coefficient**	**St. error**
ρ_O (price of oil)	0.75	0.07	0.80	0.07
ρ_G (price of natural gas)	0.81	0.01	0.76	0.09
ρ_C (price of coal)	0.58	0.12	0.65	0.10

Source: KAPSARC.

Finally, Table B2.5 shows the covariance matrix for the residuals of the regressions. As in the U.S., the results suggest that oil shocks, natural gas shocks and coal shocks are not independent.

Table B2.5. Covariance matrix for the errors.

	Germany			U.K.		
	ε^O_t	ε^G_t	ε^C_t	ε^O_t	ε^G_t	ε^C_t
ε^O_t	0.08	0.04	0.04	0.06	0.04	0.02
ε^G_t		0.05	0.03		0.08	0.04
ε^C_t			0.05			0.04

Source: KAPSARC.

Appendix C: Description of the Data

Data for national primary energy consumption and international fossil fuel prices were obtained from BP (2014). We used Brent as the representative price of crude oil for Germany and the U.K. and West Texas Intermediate for the U.S.

Coal prices were generated differently. We used the Central Appalachian coal spot price as the reference price for the U.S. from 1980 to 2013. For German and the U.K. coal prices, for 1987-2013 we used the Northwest Europe marker as the representative price and for 1980-1986 we used the sea-borne U.S. Central Appalachian coal spot price as a reference for price movements in Europe, assuming that both series have similar annual rates of growth.

In the case of natural gas, for the U.S. we used the Henry Hub spot price for the years 1987-2013. We used the U.S. spot wellhead gas price obtained from EIA (n.d.) for the preceding years. We used average import prices as the German benchmark price for 1984-2013. For the preceding period 1980-1983, we reverse-constructed the German price by assuming similar growth rates as the U.S. spot wellhead gas price obtained from the EIA (n.d.). In the case of the U.K., we used the NBP price for the period 1996-2014. For the preceding period 1980-1995, we reverse-constructed the U.K. price by assuming similar growth rates as the German prices.

All prices for the three fuels were converted to real terms using country-specific deflators.

The U.S., German and U.K. gross domestic products (GDPs), in both real and nominal terms, were sourced from The World Bank macroeconomic database, complemented by data on the share of labor as percentage of GDP taken from the European Commission database (AMECO, n.d.).

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About the project

The KAPSARC Energy Vulnerability project looks at analyzing energy shocks and disruptions from the perspective of both exporting and importing economies. The project’s objective is to understand what are the macroeconomic fundamentals that increase the resilience of a country to energy shocks and, in particular, the role of the energy mix in reducing vulnerability. The research will be complemented by an analysis of policies that enhance the resilience of economies to energy shocks.

Notes

Notes

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