Energy endowments and the location of manufacturing firms

Abstract

This paper provides empirical evidence on whether individual firms choose to structure their production globally to exploit international differences in energy resources and prices. We use the US shale gas revolution as a quasi-natural experiment to analyse two extensive margins of adjustment by heterogeneous UK firms. First, we consider whether energy intensive UK firms have established new affiliates in the US in response to the shale gas shock. Second, we explore within-firm plant-level adjustments to consider whether the energy price gap increases the propensity for firms that have US operations to shut down their energy intensive UK plants. We find evidence in support of these two margins of adjustment. Taken together, these results suggest that multinational firms have relocated energy intensive production from the UK to the US due to the endowment-driven energy price gap.

Key words

FDI, Energy endowments, Plant location, Heterogeneous firms

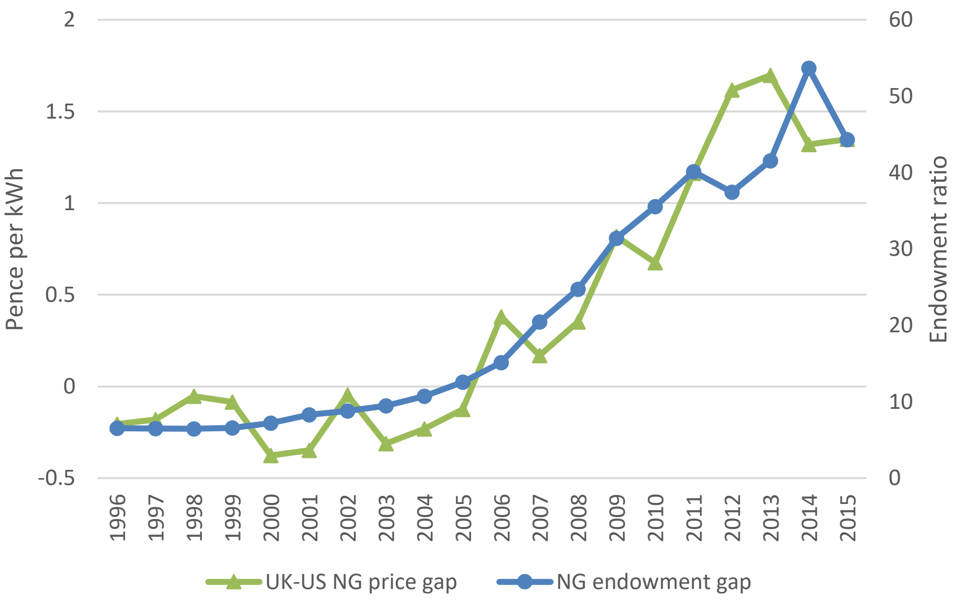
JEL classification

F21, D22, F23, Q33, O13

1. Introduction

Over recent years, trends in energy prices and energy independence have diverged across developed countries. In the US, the development of hydraulic fracturing (fracking) techniques has led to a considerable increase in the supply, and corresponding fall in the price, of natural gas and petroleum liquids. This contrasts with an increased reliance on energy imports in many other OECD countries, most notably in Europe. To take one example, the UK's endowment of natural gas and oil has been in steady decline as the North Sea oil and gas fields have matured. Imported fuels are relatively expensive due to the economic costs of transportation, especially in the case of natural gas. Therefore, industrial natural gas prices are now around 2.6 times higher in the UK than the US (on average for 2012-2015). Figure 1 illustrates the close relationship between the natural gas endowment gap and the absolute price gap for the UK-US, while Figure 2 shows the contrasting trends in dependency on energy imports for the two countries.[1]

Figure 1: UK-US natural gas endowment gap and price gap



Notes: On the left axis the figure shows the UK-US absolute natural gas price gap, calculated using industrial gas price data from the IEA. On the right axis the figure shows the US-UK natural gas endowment ratio. UK energy endowment data are from the Office for National Statistics environmental accounts. US energy endowment data are from the US Energy Information Administration.

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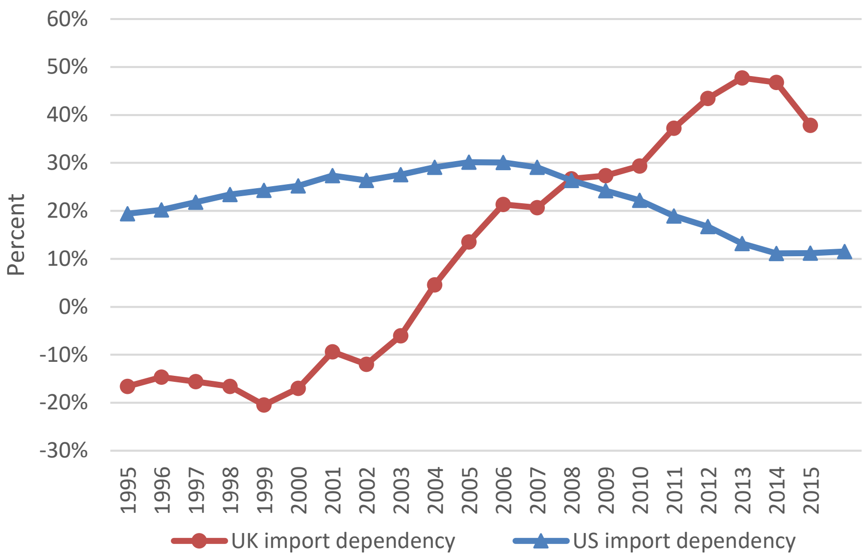
[1] At the time of writing there has been no commercial shale gas drilling in the UK, despite the UK government being supportive of shale gas development. The lack of fracking in the UK has been attributed to various factors, including that the most of suitable fracking sites are located under densely populated cities, and that rights to oil and gas deposits belong to the British crown and not landowners (unlike in the US) (Economist, 2015).

Figure 2: UK and US dependency on energy imports



Notes: Figure shows percentage of total energy supply from net energy imports in UK and US. Authors' calculations using data from Eurostat and the US Energy Information Administration.

A number of business leaders and analysts have expressed concerns about the effect of the energy price gap with the US on the international competitiveness of European firms, raising the possibility that they will either shut down, or move to the US in order to take advantage of lower energy costs. For example, the International Energy Agency suggests that the energy price gap with the US will hurt Europe's competitiveness for "at least 20 years".[2] Likewise, according to the Chief Executive of Eon, Johannes Teyssen: "There is no near-term cure for Europe's energy price gap with the US...Companies will continue to move overseas as a result." "The price difference is unnerving some companies and deciding their investments."[3] Predictions of this type follow directly from theories of vertical foreign direct investment (FDI), where international differences in factor endowments influence the pattern of investment and firms locate different stages of the production process according to where the factors used intensively in production are relatively cheap.

In this paper, we investigate whether firms behave in this way using the US energy revolution as a quasi-natural experiment, and rich micro data on the FDI decisions and energy consumption of individual UK manufacturing firms. Our results suggest that UK firms have adjusted to the US energy endowment shock at two extensive margins. First, we find that energy intensive UK firms have established new affiliates in the US in response to the endowment-driven energy price gap.

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[2] Inset from article in Financial Times on January 29th 2014. See https://www.ft.com.

[3] Insert from articles in Financial Times on September 29th 2013 and October 13th 2013. See https://www.ft.com.

We find that this effect is strongest for firms with the most energy intensive manufacturing units. When measuring energy intensity as an average across all UK manufacturing units owned by a firm, there is a much weaker effect on the firm's decision to invest in the US. These results suggest that it is important to take within-firm differences in energy intensity into account when modelling firm-level FDI decisions in the presence of energy endowment shocks. We find the results are robust to various concerns about omitted variables, measurement issues and pre-existing trends. In a falsification test, we also show that the US energy endowment shock does not explain UK outward FDI into other European countries. These findings support the interpretation of our results as the causal effect of the US energy endowment shock on UK FDI into the US.

Second, we find evidence that the endowment-driven energy price gap between the UK and US has led to the increased closure of energy intensive UK plants. Relative to a control group of multinational firms that are not investing in the US, we find that US investors are more likely to shut their energy intensive UK plants after the energy price gap emerges. This result holds when we control for unobserved firm heterogeneity and is robust to alternative measures of the energy price gap. These findings provide justification for the fear that the growth of US fracking has led to the relocation of energy intensive production from the UK to the US. More generally, the results provide new evidence on the relationship between input costs and the location of manufacturing plants.

This paper contributes to various strands of the existing literature. First, we add to work that investigates whether energy prices are a source of comparative advantage and therefore affect international trade and investment. This literature focuses mostly on industry level trade responses, rather than firm level investment decisions. Arezki et al. (2017) investigate the impact of the US shale gas revolution on the production and trade patterns of US manufacturing industries. They estimate that lower relative natural gas prices led US exports to increase by more than $100 billion for energy intensive manufacturing in 2012. Other studies that investigate the effect of energy prices on exports at the industry level include Aldy and Pizer (2015) and Sato and Dechezlepretre (2015). One study on FDI effects is Saussay and Sato (2018). They consider the impact of energy prices on (2-digit) industry level mergers and acquisitions for a panel of 41 countries. We are the first study in this literature to investigate the micro level investment decisions of individual firms that are heterogeneous in their use of energy. This approach is important to understand the mechanisms underlying the industry level responses previously identified. Only a few studies have previously considered the relationship between energy prices and firm-level investment decisions, including Ratti et al. (2011) and Panhans et al. (2017). Due to a lack of disaggregated data on the energy intensity of individual firms or a quasi-experimental setting, these studies base identification of such effects on national variation in energy prices across many countries. Such an approach makes it impossible to rule out other country-time specific confounders as drivers of this correlation.[4]

Second, we add to the more general literature on the determinants of outward FDI. There are several studies that analyse the comparative advantage motive for FDI – namely, that international differences in factor endowments influence the pattern of investment according to the factor intensity of production (e.g. Eaton and Tamura (1994), Yeaple (2003) and Alfaro and Charlton (2009)). We add to this literature by adopting a novel test of the comparative advantage motive: we exploit a quasi-natural experiment in the form of a shock to a single country's (the US) endowment of an input to production (energy). We then use this to study the effect on the outward FDI behaviour of firms that are heterogeneous in their intensity of use in this factor of production. To the best our knowledge this has not been done before.

Third, we contribute to the literature on the effect of outward investment on the home-country operations of multinational firms. This literature largely focuses on the role of international wage differentials (Braconier and Ekholm, 2000; Head and Ries, 2002; Muendler and Becker, 2010; Harrison and McMillan, 2011; Simpson, 2012), motivated by concerns that multinationals offshore low-wage, labour intensive production to economies with lower labour costs. Developing countries are less likely to be attractive destinations for FDI in capital intensive industries, as they are typically capital scarce. Thus, we add to the literature by examining FDI between developed countries with similar capital-abundancy and labour markets, but with very different relative prices for a different input to production (energy). Energy prices may be an important consideration for the location of capital-intensive firms – which are also usually energy intensive – and thus may provide an alternative motive for offshoring production than international differences in wages. To the best of our knowledge, no previous studies on the effects of outward FDI on the home-country operations of firms have considered this motive.

The rest of this paper proceeds as follows. In section 2 we set out the econometric approach. Section 3 describes our dataset and presents summary statistics. Section 4 gives the results of the analysis. Section 5 concludes.

2. Empirical Methodology

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[4] A related literature considers the impact of energy prices on domestic competitiveness by examining the location decision of energy intensive production within the US. This literature includes Michielsen (2011) and Kahn and Mansur (2013). We extend these studies to the international context by looking at relocation between the UK and US.

In this section we present the empirical specifications we estimate to explore the effect of the US energy endowment shock on the location decisions of UK manufacturing firms.

2.1 Firm investment in US

For the first stage of our analysis, we empirically model the decision by UK manufacturing firms to invest in the US; that is, operate a US affiliate or branch. We use this framework to consider whether energy intensive UK firms have established new affiliates in the US due to the shale gas shock. We adopt a differences-in-differences approach that compares the propensity to invest in the US before and after the UK-US energy price gap emerges, and for energy intensive versus non-energy intensive firms.[5]

The energy intensity of a firm's operations at home in the UK may of course be affected by its decision to invest in the US. To remove such effects, we fix the firm's energy intensity equal to its energy intensity at the beginning of the sample period. We also check the robustness of our results to different definitions of firm energy intensity (see section 3). To remove the confounding influence of time-invariant observed and unobserved firm heterogeneity that may affect the likelihood that the firm invests in the US, we focus on a model with firm fixed effects.

Our empirical strategy also addresses the critique of differences-in-differences put forward by Bertrand et al. (2004); namely, that when using many years of data, standard errors will likely be inconsistent due to serially correlated outcomes. Furthermore, they find that econometric corrections that place a parametric form on the time-series process do not perform well. This problem is especially relevant in the context of our analysis, because the substantial sunk costs involved with establishing a new foreign affiliate or branch (such as contract negotiations and market research) mean that it is unlikely that firms respond quickly to price changes, such as energy price shocks. Thus, the decision to operate a plant in the US is highly persistent and varies little on an annual basis.

We adopt two estimation methods to deal with these issues. In the first estimation approach, we model the cumulative effect of all decisions to establish new foreign affiliates in the US in the post-fracking period. We do this by collapsing the time series information down to two observations for each firm, which capture the propensity to invest in the US before and after the fracking shock

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[5] In our analysis we do not exploit spatial variation in energy prices within the US. This is because the US shale gas revolution has had nationwide impacts, and our FDI data do not provide information on within-country location decisions. Nonetheless, energy prices, especially electricity prices, do vary within the US. The location within the US of affiliates established by energy intensive UK firms may to some extent be influenced by these differences. For evidence on the regional specialisation in energy intensive industries within the US, see Michielsen (2011) and Kahn and Mansur (2013).

to the energy price gap. As shown in Figure 1 above, the natural gas price gap started to emerge in 2006 when US natural gas prices first became lower than UK prices. Given that the price gap is plausibly unanticipated, we use 2006 as our baseline year. We then estimate a long interval that compares the propensity to operate US affiliates in 2006 to 2015. We choose 2015 as the post-energy shock year as it is the most recent year for which we have FDI data, giving firms the longest possible time to respond to the energy price gap.

Bertrand et al. (2004) find that collapsing data to a pre and post period performs well as a solution to the serial correlation problem. In addition, the long interval approach is appealing because it allows us to focus on the long-run effect of the US energy revolution, rather than identifying year-to-year adjustments in FDI using annual data. This is consistent with our expectation that comparative advantage does not to vary substantially from one year to the next.

We estimate the following regression equation using data at the firm level for the long interval between 2006 and 2015:

$$USFDI_{kt}^{j} = a_k + \pi_1 Post_t \times EnergyIntensity_k + d_{j,t} + \varepsilon_{kt} \qquad (1)$$

where $USFDI_{kt}^{j}$ is a dummy variable that takes a value of 1 if UK firm *k* in sector *j* has a foreign affiliate in the US in time period *t* and 0 if it does not. a_k is a firm fixed effect, $Post_t$ is a dummy variable that equals 1 for the post-energy shock year (2015) and 0 for the baseline year (2006). $d_{j,t}$ is a vector of time-varying 2-digit sector effects that capture unobserved sector-specific trends (such as regulatory changes or demand shocks). $EnergyIntensity_k$ is a continuous variable that measures the pre-determined energy intensity of the firm in the UK. As $EnergyIntensity_k$ is time-invariant, the direct effect of this term is captured by the firm fixed effect and is therefore not included in (1). Likewise, the $Post_t$ variable does not enter in (1) directly because it is captured by the sector-time dummies. Finally, ε_{kt} is a robust error term. More details on the definitions of the variables are provided in section 3.

Equation (1) is a standard difference-in-differences model, although it exploits a treatment intensity in the form of the energy intensity of the firm. The key parameter of interest is π_1 on the interaction term between $Post_t$ and $EnergyIntensity_k$. This interaction term captures the heterogeneous impact of the reduction in relative energy prices in the US on the incentive to invest in the US across different UK manufacturing firms according to their energy intensity of production. A positive and significant coefficient would suggest that energy intensive UK firms are significantly more likely to invest in the US in the post-energy shock time period. The inclusion of time-varying sector dummies means that identification comes from within-sector variation in the energy intensity of firms.

For our long interval approach, we use only two periods of data and so we estimate equation (1) in first differences. First differencing eliminates the firm fixed effect a_k. Therefore equation (1) becomes:

$$\Delta USFDI_{\mathrm{k}} = \pi_1 EnergyIntensity_k + d_j + \Delta\varepsilon_k \qquad \text{(1a)}$$

Where we estimate (1a) using OLS. As before, a positive and significant coefficient on π_1 suggests firms are entering US investment to take advantage of the US energy endowment and price shock. We also estimate alternative specifications that allow us to consider the robustness of our results to the probit estimator (see section 4).

The underlying assumption when estimating (1a) is that in the absence of the endowment-driven shock to relative energy prices, the propensity for UK energy intensive firms to invest in the US should be the same over time, relative to non-energy intensive firms, conditional on the firm fixed effects. If the common trends assumption is violated, our analysis will not capture a causal relationship. While controlling for sector specific trends, such that identification comes from within-sector variation in firm energy intensity, may mitigate any spurious effects, we adopt a number of approaches to address these concerns.

First, we consider a falsification test – we look at whether the US energy shock affected UK outward FDI into countries that had no energy endowment shock. As energy prices in the EU have moved closely with energy prices in the UK, we use the OECD EU countries for this falsification test. In the absence of spurious confounders, we should of course expect to find no statistically significant and positive effect of the interaction term between $Post_t$ and $EnergyIntensity_k$. If instead there is a positive and significant effect for the EU investment decision, it suggests the results for the US are not driven by the US endowment-driven price gap, but alternatively reflect a trend towards more outward FDI by energy intensive UK firms into all OECD countries. This might be driven by some other motivation that varies over time and is correlated with firm energy intensity. As a second approach, we test the common trends assumption by performing a test which looks for an effect of the interaction term of interest in the same long-difference model (1a) estimated for the pre-sample period. The absence of a significant pre-existing trend, particularly a positive trend, would support the interpretation of our results for the US FDI decision as the casual effect of the UK-US energy price gap.

Notwithstanding the persistence of the FDI decision, a natural concern is whether the results are robust to alternative choices for the comparison years before and after the US energy price shock. Measurement error in the FDI variable or transitory shocks may mean that these years are not representative of FDI decisions before and after the price adjustment. Furthermore, if the assumption of no anticipatory effects is invalid, energy intensive firms may have already switched into US investment by 2006 due to the energy price gap.

Our second estimation approach aims to address these concerns by using annual data to flexibly reveal the dynamics of the evolution of the US FDI decision and its correlation with the firm's energy intensity. This empirical exercise allows us to consider when UK energy intensive firms are switching into US investment, and to examine whether 2006 and 2015 are representative of FDI positions before and after the energy price shock. The empirical specification takes the following form:

$$USFDI_{kt}^{j} = a_k + \sum_t \delta_t \times EnergyIntensity_k + d_{j,t} + v_{kt} \qquad (2)$$

Where δ_t is a vector of coefficients for each year in our sample. Other variables are defined as above. Equation (2) is a firm fixed effects model estimated in levels for the period 2002-2015. We present the results by plotting the estimates δ_t graphically and we compare to the coefficients from the estimation of the same specification for the EU FDI decision.

2.2 Plant exit in UK

For the second stage of our analysis, we consider whether there is evidence that firms investing in the US are shutting down their energy intensive production in the UK in response to the endowment-driven energy price gap. Multinational firms typically operate multiple plants in the UK that vary in their energy intensity of production. Therefore, for the exit analysis we exploit within-firm, plant level data. We use annual data for the period 2002-2015, which allows us to compare the propensity to exit both before and after the UK-US energy price gap emerges. To measure the energy intensity of the plant we use energy intensity for the 5-digit industry in which the plant operates (see section 3.2).

To analyse the closure of energy intensive UK plants, we estimate a hazard model of plant survival. Hazard models use information on the duration of plant survival and so take into account that conditional survival rates may vary over the plant survival spell. In addition, they naturally account for the right-censoring of observations (the fact that information on plant survival spells is incomplete because some plants remain in operation by the end of our sample period).[6]

In our data, entry and exit is only observed in discrete one-year intervals, such that it is not possible to order plant survival times within years. As a result, there are a significant number of tied survival times, which can lead to biased coefficients and standard errors in continuous-time hazard models, such as the popular Cox proportional hazard model (Cox and Oakes, 1984). To address the problem of tied failure times, we utilise the discrete time analogue of the Cox proportional hazard model. In this case the discrete time hazard rate *h* of the plant survival spell ending (plant exit) in *m* years, conditional on survival for *m*-1 years, follows a complementary log-log (cloglog) distribution:

$$h(m, X) = 1 - \exp[-\exp(X\beta + \gamma_m)] \quad (3)$$

Where X is a vector of time-varying plant characteristics that are related to the hazard rate and γ_m is the baseline hazard. We model the baseline hazard non-parametrically by including duration-interval-specific fixed effects that allow for unrestricted changes in the hazard rate over time.

Our identification strategy involves comparing the propensity to close plants according to their energy intensity, across firms that invest in the US and a control group of firms that do not, and over time as the UK-US energy price gap emerges, conditional on observable plant characteristics. We make this comparison by including the following vector of covariates in (3):

$$X\beta = Z_{pt}\beta + \pi_0 PriceGap_t + \pi_1 EnergyIntensity_j + \pi_2 USFDI_{kt} + \pi_3 PriceGap_t * EnergyIntensity_j + \pi_4 USFDI_{kt} * EnergyIntensity_j + \pi_5 USFDI_{kt} * PriceGap_t + \pi_6 USFDI_{kt} * PriceGap_t * EnergyIntensity_j \quad (4)$$

where *p* represents the plant, *t* is the time period, *j* is the industry in which the plant operates, and *k* is the firm. Z_{pt} is a vector of plant characteristics that are related to the propensity for plants to exit. $EnergyIntensity_j$ is a time-invariant and continuous measure of the energy intensity of industry *j* in which the plant operates. As in the first stage of our analysis, we use the (time-invariant) energy intensity that prevails at the beginning of the sample period to guard against potential endogeneity bias. $USFDI_{kt}$ is a dummy that equals 1 if the firm invests in the US and 0 for a control group of firms that do not invest in the US. Firms that invest in the US may simultaneously be conducting outward FDI in other countries. Finally, $PriceGap_t$ is the annual gap in energy prices between the UK and US.

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[6] See Manjon-Antolin and Arauzo-Carod (2008) for a survey of the use of hazard models in the firm survival literature.

The main coefficient of interest in equation (4) is π_6 on the interaction between the $USFDI_{kt}$ indicator, the $PriceGap_t$ continuous variable and the $EnergyIntensity_j$ continuous variable. The estimated coefficient on this interaction term captures evidence that firms investing in the US are more likely to shut down their energy intensive UK plants than non-US investors in response to an increase in the energy price gap. The analysis is akin to a triple difference specification. Thus, if π_6 in equation (4) is statistically significant and positive, it will be consistent with the hypothesis that energy intensive UK plants owned by US investors face a greater hazard rate of exit due to the energy price gap.

We compare firms investing in the US with a control group that consists of multinational firms that are engaged in outward FDI, but not in the US. The assumption made here is that, in the absence of the US energy endowment shock, plant exit by multinational firms investing in the US would have evolved in a similar way over time to plant exit by firms conducting non-US outward FDI. Non-US investors should provide a closer comparison group than a larger control group of firms that also includes, say, purely domestic firms. Even with a comparison group of similar firms, however, the decision to invest in the US may be related to unobserved characteristics that also affect the propensity to exit, resulting in an endogeneity bias. To mitigate this concern, we also estimate a linear exit probability model with firm fixed effects. This approach allows us to exploit the time dimension of the data to control for time-invariant unobservable firm-level characteristics that may be correlated with decision to invest in the US.

3. Data and Descriptive Statistics

3.1 Overseas investment

We use data on overseas investment by UK-based firms from the Annual Inquiry into Foreign Direct Investment (AFDI), collected by the Office for National Statistics. The AFDI register provides annual information on the full population of firms conducting outward FDI from the UK, and the geographic location of their foreign affiliates or branches. Here, foreign affiliates include subsidiaries and associates.[7] For the first stage of our analysis, we use these data to construct an indicator for UK firms that invest in the US (EU), defined as firms that own at least one affiliate or branch in the US (EU) each year. The ownership of an affiliate or branch captures

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[7] A subsidiary is an overseas company where the investor holds over 50% of the voting power and so can exercise a dominant influence. An associate is an overseas company where the parent holds between 10% and 50% of the voting power. Both subsidiaries and associates are defined as affiliates. In contrast to an affiliate, a foreign branch is a permanent establishment that is not a separate legal entity.

a fixed capital investment.[8] We also use the AFDI register to derive the counter-factual group in the second stage of our analysis, i.e. firms that invest abroad but not in the US. When deriving this group, we follow Simpson (2012) and exclude overseas affiliates or branches in countries that are designated as tax havens.

Although the AFDI register includes outward investments by both domestic and foreign owned UK firms, when estimating equations (1) and (3) above we focus on the sub-sample of firms that are UK owned. Foreign owned firms may behave quite differently to domestically owned firms in terms of their outward investment decisions, for various reasons. Most importantly, foreign owned UK firms are already multinational, even if the UK firm does not itself engage in outward FDI. In addition, we are unable to observe the full set of outward FDI destinations for the foreign parents of such firms – for example, in which other countries French firms have overseas affiliates.

3.2 Firm and plant characteristics

The second data source used in this analysis is the Annual Respondents Database (ARD), which is the largest and most comprehensive source of UK business micro-data collected by the Office for National Statistics. The ARD data can be linked to the AFDI register at the firm level using unique firm identifiers found in both datasets.[9] We use data from the ARD annual production survey, which provides detailed information on inputs and output for a sample of UK reporting units.[10] The survey covers approximately 10,000 reporting units in the manufacturing sector every year, including a census of all reporting units with 250 employees or more, and a random sample of smaller reporting units.[11] From the ARD production survey, we use information on reporting unit energy expenditures in the manufacturing sector to measure energy intensity. We follow previous studies (Martin et al. 2012; Martin et al. 2014) by considering two definitions of energy intensity: (*i*) energy expenditure as a share of gross output; and (*ii*) energy expenditure as a share of variable costs (including materials, energy and wages).

A concern regarding the measure of energy expenditure as a share of gross output is that it will be affected by differences in the price-cost mark-up across firms, given that output is measured in

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[8] The AFDI register does not provide any information on affiliate size. However, the AFDI register provides the sampling frame for the AFDI survey, that collects annual financial data on overseas activities for a sample of UK multinational firms. We do not use the data on financial transactions as we are concerned that financial and accounting variables may not reflect actual capital investments.

[9] Criscuolo and Martin (2009), Simpson (2012) and Harris and Moffat (2016), among others, also use these linked data.

[10] Firms often own multiple reporting units. In turn, a reporting unit can report on behalf of one or more local units (plants) in the same line of business.

[11] The random sampling of smaller reporting units includes a 50% or 100% sample of reporting units with between 100 and 249 employees, where the fraction varies by industry, a 50% sample of reporting units with 10 to 99 employees, and a 25% sample of reporting units with fewer than 10 employees.

value units. Therefore, energy expenditure as a share of costs may be preferred, although there may be a related problem with input price variations across firms that also affect this measure. If energy expenditure as a share of costs is correlated with heterogeneous input prices, our analysis may in part capture something else that changed in the US economy over time that affects the decision to invest through the input price channel. Unfortunately, our dataset does not contain information on the prices firms charge for their output or pay for their inputs, so we cannot rule out these alternative explanations. However, we do have information on the quantity of labour, and so we calculate the average wage by dividing the value of wages by the number of employees. We find the correlation between the average wage and the energy intensity is very low (for example, the correlation is 0.02 across reporting units in 2006). This suggests that, at least for the average price of labour inputs, the input price channel may not affect our results.

While energy intensity from the ARD survey is calculated at the reporting unit level, in the first stage of our analysis we use a time-invariant measure of energy intensity at the firm level (see section 2.1 above). To calculate this measure we first average the energy intensity of each ARD reporting unit over the period 2005 to 2008. We check the robustness of our results to averaging over 2002 to 2005, although averaging over the earlier period leads to a loss of sample size (when estimating the 2006 to 2015 long interval). We average the energy intensity variable over time to mitigate the effect of annual fluctuations in energy intensity that may take place each year, whether specific to an individual reporting unit or driven by an industry-specific shock.[12]

Using the average energy intensity of each reporting unit, we then consider two approaches to calculating firm level energy intensity. First, we take the energy intensity of the firm's most energy intensive reporting unit (maximum energy intensity). This approach is appropriate if a firm's decision to invest in the US is driven by its most energy intensive line of production. Second, we take the overall energy intensity of the firm (by calculating the weighted average energy intensity across all the firm's reporting units in the manufacturing sector). This measure is appropriate if investment decisions made by a firm are driven by the average energy intensity of its manufacturing activities. From the reporting unit level data, we also identify the modal 2-digit sector in which the firm has UK operations for the construction of the firm-level sector-time trends.

For the second stage of our analysis on the plant exit decision in the UK, using the reporting unit data from the ARD sample is problematic. First, reporting units in the ARD sample often provide energy expenditure data on behalf of multiple plants (local units), in order to reduce the compliance

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[12] When calculating the reporting unit's average energy intensity we exclude outliers (when energy intensity is measured as greater than 0.8).

costs of the survey. Therefore, exit of an individual plant may not be captured at the reporting unit level for multi-plant reporting units. The ARD sample is also structured such that the probability of being sampled decreases the smaller the reporting unit, and so will to some extent under-represent smaller reporting units that are most likely to exit. Second, the energy intensity data are only observed for reporting units that survive.

To address these concerns, we analyse exit at the plant level using data on the full population of UK plants, known as local units (rather than the ARD reporting unit sample). Plants are economic units rather than accounting units. Other studies in the literature on plant exit in the UK also take the approach of using the local unit population from the ARD (e.g. Simpson, 2012; Martin et al. 2014). This allows us to capture exit of plants (local units) within reporting units. The ARD local unit data contains information on the population of UK plants through to 2015. From these data we can calculate the plant survival spell through to 2014, where a plant survival spell ends in year t if t is the final year in which the plant is observed in the population. Thus our sample period for the survival analysis is 2002-2014. We then measure energy intensity at the 5-digit industry level. This allows us to work with the full population of local units, since we observe a 5-digit industry code for all plants. To calculate the energy intensity of 5-digit industries, we aggregate the reporting unit level data on energy intensity to the industry level, using appropriate sampling weights. We fix the industry energy intensity equal to its value at the beginning of the sample period, in order to mitigate the potentially endogenous adjustment in the energy intensity of UK industries over time.

From the plant population data, we can also construct control variables for plant size (employment), labour productivity, and firm structure, which the existing literature suggests may also affect the propensity to exit (Simpson, 2012; Bernard and Jensen, 2007).[13] For firm structure we construct two indicators for multi-plant firms: a dummy for whether a plant is owned by a firm with other plants in the same 5-digit manufacturing industry ($Multi\_ind$); and a dummy for whether a plant is owned by a firm with plants in other 5-digit manufacturing industries ($Multi\_man$).

3.3 Energy prices

For the estimation of the second stage regression equation (3), we need an annual measure of the endowment-driven energy price gap between the US and UK. We consider two approaches. First, we use the UK-US natural gas price gap. Arezki et al. (2017) argue that the natural gas price gap between the US and OECD EU countries can econometrically serve as a measure of the

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[13] To calculate labour productivity we use output from the corresponding reporting unit population dataset. Thus all plants owned by the same reporting unit will have the same labour productivity in a given year.

exogenous US energy endowment shock. By a similar argument, Figure 1 suggests that the natural gas price gap between the UK and US can serve as a measure of the US energy endowment shock – and absence of a US-style energy endowment shock in the UK. Second, we use the overall energy price measure recently developed by Sato et al. (2018). They compile a measure of overall energy prices using a weighted average of the energy prices *P* for four energy fuel types *q* (oil, gas, coal and electricity). The energy price index is defined as follows:

$$EP_{ikt} = \sum_{q} W_{ikt}^{q} \times \log(P_{it}^{q})$$

where:

$$W_{ikt}^{q} = \sum_{q} \frac{F_{ikt}^{q}}{\sum_{q} F_{ikt}^{q}}$$

where F_{ikt}^{q} is the consumption of fuel type *q* in sector *k* in country *i*, and in time period *t* and P_{it}^{q} is the real fuel price. As adjustments in energy consumption may respond endogenously to the energy price, we use the index with the weights fixed over time based on data from 2005. From this index we then derive the overall energy price gap between the UK and US by sector. The advantage of the Sato et al. (2018) index is that it allows us to take into account the price gaps for all fuels, not just natural gas prices. It also allows us to model the heterogeneous effect of the energy price gap across sectors due to sector differences in the composition of energy consumption.

Descriptive statistics for the overall energy price gap are provided for a selection of sectors in Figure A1 in the Appendix. Figure A2 in the Appendix shows that the overall energy price gap for manufacturing is highly correlated with the natural gas price gap. They are closely related because natural gas is the biggest source of energy consumption for UK manufacturing and possibilities for interfuel substitution mean that lower relative natural gas prices will lead to lower relative prices for energy substitutes. In addition, the natural gas price gap has a direct effect on relative electricity prices because a major source of electricity generation in both the UK and US is gas-fired generation.

3.4 Descriptive Statistics

Table 1 below gives summary statistics for the energy intensity of reporting units observed at the beginning of the long interval i.e., averaged over 2005-2008. The most energy intensive 2-digit sectors are highlighted in bold in panel B. They include other non-metallic mineral products, recycling, basic metals, and pulp and paper. However, there is a substantial degree of variation in the energy intensity of reporting units within sectors, which supports the value of a highly disaggregated analysis.

Table 1: Summary statistics for reporting unit energy intensity

Panel A. All manufacturing

Definition	Mean	SD	SD, between 2-digit	SD, within 2-digit	Observations
Energy Exp/Output	0.021	0.027	0.011	0.026	18,175
Energy Exp / Variable Costs	0.024	0.025	0.012	0.024	18,175

Panel B. Energy expenditure / Variable Costs by 2-digit industry

SIC	Description	Mean	SD	P10	P90	Observations
15 & 16	Food products, beverages and tobacco products	0.030	0.023	0.010	0.057	1,680
17	Textiles	0.029	0.024	0.008	0.056	678
18	Wearing Apparel	0.015	0.032	0.002	0.027	391
19	Leather and leather products	0.013	0.011	0.003	0.025	104
20	Wood and wood products	0.023	0.019	0.007	0.043	628
21	**Pulp and paper**	**0.032**	**0.033**	**0.011**	**0.078**	**497**
22	Publishing and printing	0.016	0.012	0.003	0.032	1,717
23	Coke and refined petroleum products	0.030	0.040	0.000	0.085	59
24	**Chemicals and chemical products**	**0.031**	**0.037**	**0.007**	**0.064**	**901**
25	Rubber and plastic products	0.029	0.016	0.013	0.047	1,207
26	**Other non-metallic mineral products**	**0.058**	**0.056**	**0.014**	**0.128**	**668**
27	**Basic metals**	**0.035**	**0.025**	**0.009**	**0.064**	**486**
28	Fabricated metal products	0.026	0.023	0.009	0.047	2,649
29	Machinery and equipment nec	0.019	0.016	0.006	0.034	1,964
30	Electrical and optical equipment	0.011	0.012	0.001	0.021	127
31	Electrical machinery and apparatus nec	0.014	0.012	0.005	0.025	880
32	Radio, television and communication equipment	0.017	0.017	0.004	0.036	373
33	Medical, precision and optical instruments	0.012	0.011	0.004	0.022	738
34	Motor vehicles, trailers and semi-trailers	0.018	0.023	0.006	0.029	581
35	Other transport equipment	0.019	0.022	0.004	0.033	409
36	Manufacturing nec	0.020	0.019	0.006	0.035	1,301
37	**Recycling**	**0.046**	**0.033**	**0.009**	**0.089**	**137**

Notes: Table gives summary statistics for the energy intensity of reporting units observed over the beginning-of-sample period (i.e., average energy intensity over 2005-2008). SD indicates standard deviation. P10 and P90 indicate the 10% and 90% percentile respectively. In panel B the bold rows indicate the five most energy intensive industries.

Table 2 gives the correlations between the alternative definitions of energy intensity and the different methods for aggregating from the reporting unit level to the firm level (described above in section 3.2). The maximum and overall energy intensity of firms are very highly correlated, which reflects that many firms in our sample have only a single reporting unit. However, if we consider only US investors, the correlation between the maximum and overall energy intensity is lower, as shown in panel B. This is because US investors are more likely to have multiple reporting units than purely domestic firms.

Table 2: Correlation between alternative definitions of firm-level energy intensity

	Max Energy Exp/Output	Max Energy Exp/Costs	Overall Energy Exp/Output	Overall Energy Exp/Costs
Panel A: All firms				
Max Energy Exp/Output	1.000			
Max Energy Exp/Costs	0.776	1.000		
Overall Energy Exp/Output	0.970	0.756	1.000	
Overall Energy Exp/Costs	0.755	0.976	0.773	1.000
Panel B: US investors only				
Max Energy Exp/Output	1.000			
Max Energy Exp/Costs	0.858	1.000		
Overall Energy Exp/Output	0.794	0.764	1.000	
Overall Energy Exp/Costs	0.782	0.894	0.889	1.000

Notes: Max measures the energy intensity of the firm's most energy intensive reporting unit. Overall measures the overall energy intensity of the firm. All variables measured in levels. Correlations calculated for all firms in the dataset in 2006. All correlations are significant at the 1% level.

Finally, in Table 3 we report on the characteristics of plants owned by US investors and the control group of plants owned by non-US multinationals. We find that there are a substantial number of plants that exit over our sample period of 2002-2014, with about 2,000 plants shut down by firms in each group (US and non-US investors) and the annual exit rates of plants are around 9%. We also note that plants owned by firms investing in the US are larger on average in terms of employment but are slightly less productive than non-US investors.

Table 3: Descriptive statistics of plant dataset by FDI status, 2002-2014

	US investors	Non US investors
Observations	25,499	22,602
Exit events	2,189	2,067
Exit	0.086	0.091

	(0.280)	(0.289)
Age (years)	9.072	9.287
	(5.989)	(6.246)
Employment	129.251	89.057
	(353.159)	(204.875)
Labour productivity	207.708	220.324
	(1292.312)	(3304.002)
Multi_ind	0.725	0.720
	(0.447)	(0.449)
Multi_man	0.800	0.733
	(0.400)	(0.443)
Industry energy intensity	0.021	0.023
	(0.015)	(0.015)

Notes: Calculations are averages over plants present in the population over 2002-2014. Table shows means with standard deviations in parentheses. Exit is a dummy variable equal to 1 if the plant exits in period t +1. Age is truncated at 42 years.

4. Empirical Results

4.1 Decision to invest in US

In this section we report the results for the estimation of equation (1a), which considers the decision by UK firms to open or acquire affiliates in the US over the long interval 2006 to 2015. First differencing ensures identification of the effect of the US endowment-driven energy price gap on the investment decisions of UK firms is based only on within-firm variation in FDI behaviour. By not using cross-sectional variation this is a demanding estimator that is robust to unobserved firm heterogeneity. Of the 6,061 firms in the sample, 126 firms have US affiliates in 2006 and 180 firms have US affiliates in 2015. In total, 68 new firms switch into US investment, and 14 firms switch out of US FDI. The fact that only a small proportion of the overall sample invest in the US is consistent with findings elsewhere in the heterogeneous firms literature – namely, that only the most productive firms are able to overcome the sunk costs involved with doing FDI.

The results are reported in Table 4. Estimated coefficients are shown with standard errors in parentheses. These regressions use alternative measures of energy intensity (as a ratio to output or costs) and with and without 2-digit industry controls. Columns (1) to (4) use the energy intensity of the firm's most energy intensive reporting unit. These are our baseline results. Columns (5) to (8) use the firm's overall energy intensity.[14]

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[14] We measure energy intensity in logarithmic form. The results are qualitatively similar if we measure energy intensity in levels.

In column (1) energy intensity is defined as the share of energy expenditure in gross output (turnover). In this case we find a positive effect of the energy intensity variable that is significant at the 1% level. This result suggests that UK firms with energy intensive reporting units are more likely to invest in the US after the endowment-driven energy price gap (relative to the same energy intensive firms before the price gap). This supports the hypothesis that energy intensive UK firms are engaging in FDI in order to take advantage of lower energy costs in the US. In column (2) we define energy intensity as the share of energy expenditure in variable costs. The estimated coefficient is again positive and significant at the 1% level. Columns (3) and (4) estimate the same specifications as in columns (1) and (2) but now including sector dummy variables to control for time-varying sector effects that influence outward FDI. The results are robust to the inclusion of these controls. We continue to find that UK firms with the most energy intensive reporting units are more likely to invest in the US in the post fracking period.

Table 4: First differences regressions for decision to invest in the US over 2006 to 2015 long interval

	(1) ΔUSFDI	(2) ΔUSFDI	(3) ΔUSFDI	(4) ΔUSFDI	(5) ΔUSFDI	(6) ΔUSFDI	(7) ΔUSFDI	(8) ΔUSFDI
ln(Energy Exp/Output)_k	0.005^{***}		0.006^{***}		0.002		0.004^{**}	
	(0.002)		(0.002)		(0.002)		(0.002)	
ln(Energy Exp/Costs)_k		0.006^{***}		0.008^{***}		0.002		0.003^{*}
		(0.002)		(0.002)		(0.002)		(0.002)
Observations	6061	6061	6061	6061	6061	6061	6061	6061
R^2	0.002	0.002	0.012	0.012	0.000	0.000	0.010	0.010
Mean USFDI in 2015	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Energy Intensity	Max	Max	Max	Max	Overall	Overall	Overall	Overall
2-digit sector dummies	NO	NO	YES	YES	NO	NO	YES	YES

Notes: First difference regressions for decision to invest in the US. Table shows coefficients with heteroskedasticity robust standard errors in parentheses. Columns (1) to (4) measure energy intensity as the firm's most energy intensive line of business, while columns (5) to (8) use the firm's overall energy intensity. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

We now assess the magnitude of the estimated coefficients. The standard deviation of log energy expenditure as a share of variable costs in our sample is 0.791. Therefore, the coefficient in column (4) of Table 4 implies that a 1 standard deviation increase in (log) energy intensity increases the probability of investing in the US in the post energy price shock period (relative to before the shock) of 0.791 × 0.008 = 0.006. That is, 0.6 of a percentage point.[15] A small adjustment in absolute terms is in line with our expectations because only the very best firms are sufficiently productive to overcome the sunk costs associated with establishing new affiliates abroad. The overall rate of investment in the US in the post-shock period in our sample is equal to just 2.97%. Therefore 0.6 of a percentage point represents about 20% of US FDI in the post shock period.

In Table 4 columns (5) to (8) we now measure energy intensity across all the firm's UK manufacturing operations. For these specifications we find more mixed evidence compared to the regressions using the firm's most energy intensive reporting unit. The coefficients are statistically significant only with the inclusion of the sector dummies to control for sector trends in columns (7) and (8). The estimated effect is significant only at the 10% level in column (8). The fact that we observe a strongly significant effect when using the maximum energy intensity, but not the energy intensity across all reporting units, suggests that concerns over energy consumption and costs in particular parts of the firm's production process drive the increased propensity to invest in the US. Averaging over all of the firm's operations tends to hide this relationship. These results imply that it is important to take into account within-firm heterogeneity in the energy intensity of production when analysing firm-level FDI decisions.[16]

We unpick the significant effects observed in columns (3) and (4) in Table 4 by testing whether there is an asymmetric effect of energy intensity on the decision to locate new production in the US (entry) compared to the decision to close or sell off US affiliates (exit). Table 5 reports the results of this exercise. The entry and exit specifications can be estimated using the probit estimator, allowing us to check that the results are robust to properly modelling the curvature of the regression function in the proximity of 0 and 1.

Table 5: Estimation of firm decision to enter US investment and exit from US investment

	(1) ENTRY OLS	(2) ENTRY OLS	(3) ENTRY PROBIT	(4) ENTRY PROBIT	(5) EXIT OLS	(6) EXIT OLS	(7) EXIT PROBIT	(8) EXIT PROBIT

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[15] We obtain the same magnitude from the results in column (3) of Table 4.

[16] A possible concern is that the results in Table 4 are driven by a few firms with very high energy intensities (even though we have dropped the reporting units with energy intensities greater than 0.8). However, we check the energy intensities of the 68 firms opening new plants in the US and find that none of these firms have an energy intensity greater than 0.15 (measured either as a share of output or costs). The results are also fully robust to dropping all firms with very high energy intensities (greater than, say, 0.3) from the sample. Therefore, we conclude our results are not driven by outliers.

ln(Energy Exp/Output)_k	0.006***		0.007***		-0.062**		-0.056*	
	(0.002)		(0.002)		(0.028)		(0.032)	
ln(Energy Exp/Costs)_k		0.007***		0.008***		-0.063**		-0.062*
		(0.002)		(0.002)		(0.031)		(0.036)
Observations	5,936	5,936	5,936	5,936	125	125	125	125
R^2	0.018	0.018	-	-	0.242	0.238	-	-
Pseudo R^2	-	-	0.080	0.078	-	-	0.090	0.087
Mean ENTRY / EXIT	0.011	0.011	0.011	0.011	0.112	0.112	0.112	0.112
Energy Intensity	Max	Max	Max	Max	Max	Max	Max	Max
2-digit sector dummies	YES	YES	YES	YES	YES	YES	YES	YES

Notes: Levels regressions for the decision to enter or exit from US investment by 2015. Columns (1), (2), (5) and (6) estimate OLS regressions, where coefficients are reported with heteroskedasticity robust standard errors in parentheses. Columns (3), (4), (7) and (8) estimate probit regressions, where marginal effects are reported with standard errors in parentheses. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Columns (1) to (4) in Table 5 consider the entry decision. For these regressions we drop from the sample those firms that already owned affiliates in the US in 2006, such that we use only firms that undertake FDI into the US for the first time during the sample window. The dependent variable is now in levels rather than first differences, and is defined as a dummy equal to 1 if the firm starts investing in the US by 2015, and 0 if it remains a non-US investor. Hence, identification can only come from the decision to enter US FDI. Columns (1) and (2) report OLS regressions, while columns (3) and (4) report probit regressions. As expected, the signs on the energy intensity measures are always positive, and always significant at the 1% level. The magnitudes of the coefficients are comparable to those found in Table 4. Reassuringly, the probit gives very similar results to the OLS regressions.

Columns (5) to (8) in Table 5 consider the closure of US affiliates and retain only firms that operated in the US at the start of the sample period (in 2006). Here we define the dependent variable as equal to 1 for firms that closed their US affiliates by 2015 (and a 0 for firms that remain as US-investors). We now always find a negative and significant coefficient, indicating UK owned firms with energy intensive production processes are less likely to exit from investing in the US. The coefficients are notably larger in magnitude than for the entry regressions, suggesting there are asymmetries between the two margins of adjustment. However, this finding should be treated with some caution given the standard errors have also increased substantially, which reflects the very small sample size (and that only 14 firms in the sample withdraw from US investment).

We now consider potential threats to the validity of our modelling strategy. We begin by focusing on possible unobserved determinants of FDI. As the shock to energy endowments was a US-specific event, an obvious falsification test for the above findings is to consider whether UK firms are also expanding their plants into non-US locations. If energy intensive firms are investing in the US to take advantage of the US energy endowment driven price gap, then we should find no increased propensity for energy intensive firms to locate production in non-US countries. To test whether this is the case, in Table 6 we repeat the same specifications as in Table 4 but now for the EU FDI decision. There are 145 firms in the sample investing in the EU in 2006 and 216 firms investing in the EU in 2015. 90 new firms switch into EU FDI and 19 firms switching out of EU FDI. Reassuringly, we find no evidence of a statistically significant and positive effect of the firm's maximum energy intensity on the EU investment decision. This supports the interpretation of our results as the causal effect of the US energy endowment-driven price gap.[17]

Table 6: Falsification test first differences regressions for decision to invest in the EU over 2006 to 2015 long interval

	(1) ΔEUFDI	(2) ΔEUFDI	(3) ΔEUFDI	(4) ΔEUFDI	(5) ΔEUFDI	(6) ΔEUFDI	(7) ΔEUFDI	(8) ΔEUFDI
ln(Energy Exp/Output)_k	-0.000		-0.000		-0.002		-0.002	
	(0.002)		(0.002)		(0.002)		(0.002)	
ln(Energy Exp/Costs)_k		-0.002		-0.002		-0.004**		-0.005**
		(0.002)		(0.003)		(0.002)		(0.002)
Observations	6061	6061	6061	6061	6061	6061	6061	6061
R^2	0.000	0.000	0.009	0.009	0.000	0.001	0.009	0.009
Mean EUFDI in 2015	0.036	0.036	0.036	0.036	0.036	0.036	0.036	0.036
Energy Intensity	Max	Max	Max	Max	Overall	Overall	Overall	Overall
2-digit sector dummies	NO	NO	YES	YES	NO	NO	YES	YES

Notes: First difference regressions for decision to invest in the EU. Table shows coefficients with heteroskedasticity robust standard errors in parentheses. Columns (1) to (4) measure energy intensity as the firm's most energy intensive line of business, while columns (5) to (8) use the firm's overall energy intensity. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Underlying the interpretation of the positive and significant effects found in columns (1) to (4) of Table 4 as the causal effect of the US endowment-driven energy price gap is the common trends assumption. That is, in the absence of the US energy endowment shock, the propensity to locate production in the US should be the same over time for energy intensive firms relative to non-energy intensive firms. The fact that we do not find significant results for the EU FDI decision

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[17] Table A1 in the Appendix shows falsification test results for the entry and exit regressions using the EU FDI decision.

supports the validity of this assumption. As a further test, we re-estimate our baseline specifications but using data from the period 1998-2006, which is the period before the rapid growth of US shale gas production.[18] If there is not a common trend during the pre-sample period, it suggests that our results may simply reflect a pre-existing trend unrelated to the UK-US energy price gap that emerged in the mid-2000s.

Table A2 in the Appendix reports these results. As expected, the coefficients on the energy intensity variables are now always small in magnitude and insignificant for the US investment decision. Therefore, there is no evidence of a pre-existing trend towards more FDI in the US by firms with relatively energy intensive operations. This is also the case for the EU investment decision in the pre-sample period.

We next consider whether the results are robust to constructing our measure of energy intensity in a different way. For the results in Table 4 we average the reporting unit energy intensity over 2005-2008 (see section 3.2). We consider the robustness of the results to averaging over an earlier period of 2002-2005. The results are given in the Table A3 in the Appendix. Averaging over an earlier period changes the sample of firms included in the analysis and leads to some loss of variation in the dependent variable. For the US FDI decision there are now 56 firms switching into FDI and 14 firms switching out, while for the EU FDI falsification test there are 75 firms switching into FDI and 19 firms switching out. Nonetheless, the main results are robust. There remains a positive and significant effect of the likelihood of US-bound FDI if the firm operates an energy intensive manufacturing unit in the UK in the period before the fracking boom in the US.[19]

An additional concern is that our results may capture some other time-varying effect driving US FDI, that we have wrongly attributed to the firm's energy intensity. For example, it is well known that energy intensive firms are usually capital intensive, and it may be there is an increased propensity for capital intensive firms to invest in the US over time. If this is a non-linear trend then it may not be detected in our pre-sample falsification test. We address this concern by controlling for other factor intensities of production interacted with the post-fracking dummy in the model (equation (1)). Allowing for time-varying effects of additional factor intensities is highly

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[18] We use an 8 year interval for the pre-sample period because before 1998 the AFDI register used a different coding method. We continue to measure energy intensity over the period 2005-2008 to ensure we are comparing firms with the same recorded energy intensity as that considered in Table 4. We obtain very similar results for these regressions if instead we measure energy intensity over the earliest possible four year period for which energy intensity data are available (1999-2002). These results are available on request.

[19] The overall energy intensity of the firm is now insignificant for all specifications.

demanding for our data, given that only a small number of firms undertake FDI. The results are given in Table A4 in the Appendix. Columns (1) and (2) repeat the baseline results from Table 4 with the inclusion of sector trends. Columns (3) and (4) add a further interaction term with the firm's most capital intensive line of production and columns (5) and (6) control for an interaction term with the firm's most labour intensive line of production.[20] Finally, columns (7) and (8) include all factor intensities together. Across all specifications, we continue to find the effect of the firm's energy intensity is highly significant on the likelihood of US-bound FDI. The capital intensity interaction is only weakly significant (at the 10% level) while the labour intensity interaction is always insignificant.

We next consider whether the choice of comparison years for the long interval, 2006 and 2015, are representative of FDI positions before and after the US energy endowment shock. To address this issue we turn to our second empirical exercise for modelling US and EU FDI, given by equation (2) above. Here we focus on the baseline results using the firm's most energy intensive reporting unit and using energy intensity defined as energy expenditures as a share variable costs. Full results for all measures of energy intensity for both the US and EU FDI decisions are given in Table A5 in the Appendix.[21]

Results are presented in Figure 3 below, which plots the coefficients estimated for each year relative to the omitted year (2006). The vertical lines indicate the 95% confidence interval around the coefficients for the US FDI regression. For US investment, we find the coefficients for 2002-2005 are not statistically different to 2006. There is no evidence to suggest that the propensity for energy intensive firms to conduct FDI into the US was increasing over these four years. This again demonstrates that our results for the 2006-2015 long interval do not simply reflect a positive pre-existing trend – if anything, there is a slight downward trend over this short pre-sample period. This evidence is consistent with the assumption that the energy price gap is unanticipated.

Figure 3 also shows that the coefficient on energy intensity for 2007 is larger than the coefficient for 2006 (although it remains insignificantly different at the 5% level). However, the increase in 2007 is transitory rather than a persistent adjustment, because in 2008-2012 the coefficients on energy intensity are again very close to 0. Only in 2014 and 2015 is there a clear positive effect of

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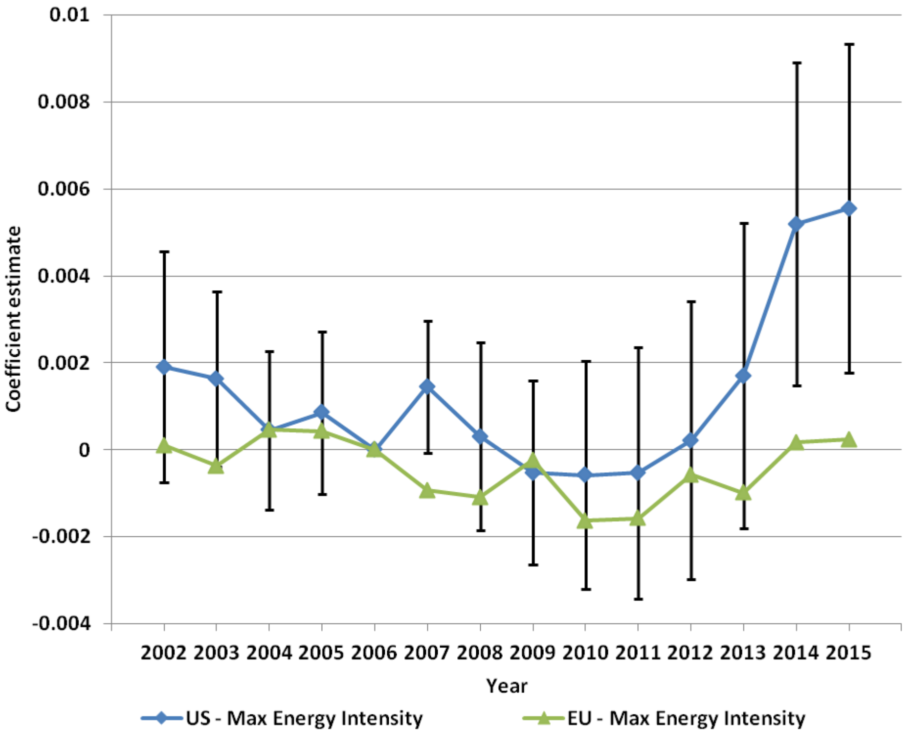
[20] Capital intensity is defined as the total capital stock per unit of output or costs Capital stocks are calculated using a perpetual inventory method (PIM) based on investment data from the ARD production survey. Labour intensity is defined as wages per unit of output or costs.

[21] We use a sample that consists of all firms, including those that exit during the sample period. We obtain similar results if we drop firms that fail, such that only the firms that survive through to 2015 are included in the sample.

energy intensity on the propensity to invest in the US. In contrast, there is no discernible increase in the propensity for energy intensive firms to invest in the EU, with the coefficients always close to zero. The fact that there is a clear positive effect for US FDI only towards the end of our sample is not surprising given there are substantial fixed costs associated with establishing new foreign plants, and so FDI decisions are likely to respond with a lag to the price gap. Moreover, firms may initially perceive any price gaps as temporary, and so view the short-term gains from locating production in the US to be not worth the costs of relocating. Only when price gaps persist may firms consider undertaking FDI.

Figure 3: Plot of coefficients giving effect of firm energy intensity on the propensity to invest in the US and EU by year



Notes: Results from non-parametric regression of the US and EU investment decision on interaction terms between firm energy intensity and a vector of year dummies, using annual data and controlling for firm fixed effects and sector-time effects. Coefficients for both US and EU investment are effects relative to the omitted year (2006), with vertical lines indicating the 95% confidence intervals for the coefficients from the US FDI regression.

4.2 Decision to close plants in UK

We now consider whether those firms undertaking FDI into the US are in turn shutting down their energy intensive plants in the UK in response to the energy price gap. Table 7 presents results from the estimation of the discrete time hazard model and the linear probability model, where we define the energy price gap as the natural gas price gap (using price data shown in Figure 1 above). In all specifications, the natural gas price gap does not enter directly into the regression, as it varies over time only and so is absorbed by year fixed effects. Likewise, the energy intensity of the industry does not enter directly as it is absorbed by industry fixed effects. For the hazard model we report estimated coefficients, rather than hazard ratios (exponentiated coefficients), to facilitate comparison with the linear probability model.

In column (1) of Table 7 we estimate the cloglog with 5-digit industry fixed effects. In column (2) we estimate the same specification using OLS and in column (3) we include firm fixed effects. Columns (4) to (6) then explore the robustness of the firm fixed effects model from column (3). In column (4) we add in 2-digit sector-year fixed effects to control for sector trends. In column (5) we estimate a highly demanding specification that includes 5-digit industry-year fixed effects to control for all observed and unobserved time-varying industry variables, such as demand shocks and the degree of import competition facing plants in the industry. Finally, in column (6) we also estimate the model with 5-digit industry-year fixed effects but we now include foreign owned multinational firms in the sample (as well as UK owned multinational firms).

Columns (1) and (2) give similar results in terms of the signs and significance of the effect of the explanatory variables. In both cases we find the coefficient on the US FDI variable is negative and significant. This result indicates that there is a lower hazard rate for plants owned by UK firms engaging in US FDI for an industry with average energy intensity (and in the absence of a UK-US natural gas price gap).[22] However, when we include firm fixed effects in columns (3) to (6) we find the US FDI variable becomes insignificant. We also find that the interaction term between $USFDI$ and $\ln(EnergyIntensity)$ is negative and significant across all specifications. This result suggests that in the absence of an energy price gap between the US and UK, firms with FDI in the US are less likely to shut down more energy intensive production (relative to non-US investors). That is, investing in the US is a complement for energy intensive UK production rather than a substitute, at least in terms of the likelihood of plant closure.

Table 7: Plant exit in UK in response to natural gas price gap between the US and UK over 2002-2014

	(1) Cloglog	(2) OLS	(3) Firm FEs	(4) Firm FEs	(5) Firm FEs	(6) Firm FEs
ln(Employment)_pt	-0.313^{***}	-0.027^{***}	-0.037^{***}	-0.037^{***}	-0.037^{***}	-0.036^{***}
	(0.020)	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)
ln(Productivity)_pt	-0.161^{***}	-0.015^{***}	-0.022^{***}	-0.020^{***}	-0.020^{***}	-0.021^{***}
	(0.027)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Multi_Ind_pt	0.335^{***}	0.026^{***}	0.038^{***}	0.039^{***}	0.039^{***}	0.041^{***}
	(0.060)	(0.005)	(0.009)	(0.008)	(0.009)	(0.009)

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[22] This follows from the fact that we scale the industry energy intensity variable by its average, such that the log energy intensity is 0 for the average industry.

Multi_Man_kt	0.282***	0.022***	0.017***	0.016***	0.014***	0.014***
	(0.051)	(0.004)	(0.005)	(0.005)	(0.005)	(0.004)
PriceGap_t*ln(Energyintensity)_j	0.077	0.005	-0.017**	-0.021**		
	(0.100)	(0.007)	(0.007)	(0.010)		
USFDI_kt	-0.132**	-0.011**	-0.007	-0.007	-0.008	-0.009
	(0.054)	(0.005)	(0.008)	(0.008)	(0.009)	(0.010)
USFDI_kt*ln(Energyintensity)_j	-0.298***	-0.030***	-0.026***	-0.032***	-0.039***	-0.040***
	(0.068)	(0.007)	(0.009)	(0.009)	(0.011)	(0.010)
USFDI_kt*PriceGap_t	0.064	0.007	0.011	0.009	0.014	0.014*
	(0.090)	(0.006)	(0.007)	(0.008)	(0.009)	(0.008)
USFDI_kt*PriceGap_t*ln(Energyintensity)_j	0.008	0.007	0.031***	0.032***	0.042***	0.042***
	(0.114)	(0.009)	(0.009)	(0.010)	(0.012)	(0.010)
Observations	48101	48101	48101	48101	47818	56903
R^2	-	0.050	0.146	0.154	0.201	0.184
Number of 5 digit industries	240	240	240	240	240	263
Region fixed effects	YES	YES	YES	YES	YES	YES
5 digit industry effects	YES	YES	YES	YES	NO	NO
Year fixed effects	YES	YES	YES	NO	NO	NO
Firm fixed effects	NO	NO	YES	YES	YES	YES
2 digit sector-year effects	NO	NO	NO	YES	NO	NO
5 digit industry-year effects	NO	NO	NO	NO	YES	YES
Foreign owned firms in sample	NO	NO	NO	NO	NO	YES

Notes: Table shows estimated coefficients with standard errors clustered at 5 digit industry level in parentheses. The specifications have a binary dependent variable that is equal to 1 in year t if t is the final year the plant is observed. All regressions control for a fully non-parametric baseline hazard function (plant survival spell effects). * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

We now turn to the interaction terms of interest, namely the interactions with the natural gas price gap. The interaction term between $PriceGap$ and $\ln(EnergyIntensity)$ indicates the effect of the UK-US energy price gap on the exit of energy intensive plants for the control group of firms that do not invest in the US. We know, by definition, that these firms have not offshored production to the US. However, they may be outsourcing energy intensive production to US-based firms that they do not own. Equally, there may also be an increase in competition for all firms owing to an increase in energy intensive imports from the US. If these channels are important, we would expect firms with no US FDI to be more likely to shut down their energy intensive UK production in response to the UK-US energy price gap. However, as shown in Table 7, we find that the interaction between $PriceGap$ and $\ln(EnergyIntensity)$ for the control group of firms is insignificant in columns (1) and (2). In addition, it is significant and negative at the 5% level in columns (3) and (4). The US energy endowment shock does not therefore appear to have increased the rate of closure for energy intensive plants owned by firms with no US FDI, and if anything there is a decreased risk of closure for such plants. Therefore, the outsourcing and import competition effects are not found to be economically important for these firms.

Turning next to those UK owned firms with US operations, we find the interaction between the US FDI variable and the natural gas price gap ($USFDI*PriceGap$) is insignificant in columns (1) to (5) and only significant at the 10% level in column (6). Hence, there is little evidence to suggest that UK owned firms investing into the US are more likely to shut down UK plants with average energy intensity in response to the US fracking shock. However, the triple interaction term between USFDI, the energy price gap and the energy intensity of the industry ($USFDI * PriceGap * \ln(EnergyIntensity)$) is always strongly significant and positive when we include firm fixed effects (columns (3) to (6)). This result suggests that firms investing in the US have responded to the US energy endowment shock by increasing their propensity to shut down energy intensive plants in the UK, relative to the control group of non-US investors, when we control for unobserved firm heterogeneity. Therefore, there does appear to be some evidence to support the concern that firms investing in the US find the UK a less attractive location for energy intensive production due to the energy price gap.

In terms of the plant-level control variables, it is reassuring that the results are as we expect. We find that bigger plants which are more productive have lower hazard rates. There is also evidence that firms are more likely to shut down plants if they own multiple plants in the same 5-digit industry, and if it they have operations in multiple 5-digit industries. In addition, the baseline hazard function (not reported) indicates that the hazard rate falls the longer the plant's survival spell. These results are consistent with those found elsewhere in the plant survival literature (e.g. Simpson, 2012).

To assess the magnitude of the coefficients estimated in Table 7, we compute the marginal effect of investing in the US on the propensity to exit UK plants at alternative values for industry energy intensity and the energy price gap. We consider the case of a high energy intensive industry, for which we use the manufacture of industrial gases (SIC 2411) in the chemicals sector. This industry is one of the most energy intensive industries in our sample with an energy cost share of 11.1%. We have 160 plant-year observations in our data for this industry. We also consider the case of the average industry which has an energy cost share of 2.4%. For the price gap, we consider the peak price gap observed in 2013 of 1.7 pence per kWh and a natural gas price gap of 0.

The marginal effects of US FDI on plant exit at these representative values are given in Table 8. We find that US FDI leads to a 5.0 percentage point increase in the propensity to exit plants in the high energy intensive industry and in the peak energy gap year (relative to the control group of firms doing outward FDI but not in the US). In the absence of the price gap, we find US investors are less likely to exit energy intensive plants by a similar magnitude. Thus, the emergence of the UK-US energy price gap is associated with an 9.6 percentage point change in the marginal effect of US FDI for high energy intensive plants. This is a substantial adjustment given the overall probability of exit is about 9%.

Table 8: Marginal effects of US FDI on plant exit in UK at representative values

	Peak natural gas price gap	No natural gas price gap
High energy intensity	0.050	-0.046
Average energy intensity	0.011	-0.007

Notes: Table shows estimated marginal effects of US investment based on coefficients estimated in column (3) in Table 7. High energy intensity reflects the energy cost share of the manufacture of industrial gases (SIC 2411) equal to 11.1%. The average energy intensity is 2.4%. The peak price gap 1.7 pence per kWh, observed in 2013.

We can further evaluate the magnitude of the marginal effect of US FDI using a back of the envelope calculation. A one standard deviation increase in energy intensity in the peak natural gas price year of 2013 increases the plant exit propensity in response to US FDI (relative to non-US investors) by 0.015. Using the total number of plants owned by US investors in 2013 (1,640 plants), this implies the additional exit of 24 plants, or 19.5% of the total number of plants that US investors exit in 2013 (124 plants). The average employment in plants that US investors shut down in 2013 is 63 employees, and so the exit of 24 plants suggests the loss of about 1,500 jobs.

We can perform a second back of the envelope calculation to evaluate the magnitude of the effect of the energy price gap on average across all plants. We calculate the average marginal effect of US FDI on plant exit for each year in our sample in which the US has lower energy prices (2006-2014). We calculate these average marginal effects using the observed values for the energy intensity of each plant and the observed natural gas price gap in each year. We then calculate the difference in each year's average marginal effect of US FDI and the average marginal effect if there were no price gap. This calculation gives a predicted increase in the propensity for US investors to exit UK plants in each year due to the price gap on average across all plants. Using the number of plants owned by US investors in each year, and the average employment in plants that are shut down by US investors in each year, we can then arrive at an overall estimate of plant exit and the resulting jobs losses. We find that the energy price gap leads US investors shut down 27 more manufacturing plants than non-US investors over 2006-2014, resulting in the loss of 1,600 UK jobs. 27 plants is 2.5% of the total number of plants that are shut down by US investors over 2006-2014. Therefore, the magnitude of the effect of the energy price gap on average across all plants is relatively small.

Rather than focusing only on the natural gas price gap, an alternative approach involves modelling the energy price gap between the US and UK as the overall energy price gap provided by Sato et al. (2018). As explained above, the overall price gap is a weighted average energy price of four fuels (oil, gas, coal and electricity) where the weights are based on fixed (time invariant) sector-specific energy consumption. Table A6 in the Appendix reports results using this measure. As the energy price gap now varies across 2-digit sectors as well as over time, it is not absorbed by the year fixed effects and so enters directly into the model when we do not include sector-time effects (columns (1) to (3)). The findings are very similar to those in Table 7. We continue to find that in the absence of an energy price gap, firms with US affiliates are less likely to shut down energy intensive UK plants. Moreover, the propensity for firms that undertake US FDI to shut down energy intensive UK plants increases significantly in the energy price gap when we include firm fixed effects (columns (3) to (6)).

4.3 Effect of US investment on energy intensity

Finally, as an extension to our analysis we investigate the effect of US FDI on the energy intensity of surviving UK manufacturing units after the emergence of the energy price gap. Analysing this intensive margin of adjustment allows us to consider if multinational firms aim to exploit the US energy price advantage by restructuring their production such that they reduce the energy intensity of their UK production mix. We estimate fixed effects regressions that use only within-reporting unit variation in energy intensity over time for identification, for the sample period 2002-2015. As with the exit decision, we compare US investors to a control group of firms conducting non-US outward FDI. The results are reported in Table A7 in the Appendix. We find the interaction between US FDI and the energy price gap does not have a significant effect on reporting unit energy intensity. Therefore, there is no evidence to suggest that the comparative disadvantage of the UK in energy intensive production vis-à-vis the US leads firms that operate in both countries to switch their surviving UK manufacturing units to less energy intensive production.

5. Conclusion

The US shale gas revolution has led to a sharp fall in US natural gas prices, while energy prices have risen elsewhere in Europe and Asia. This is because natural gas cannot be easily transported long distances, and so shocks to energy abundance can give rise to large variations in regional energy prices around the world. Concerns have grown about the competitiveness impacts of these international differences in energy prices for Europe vis-à-vis the US, especially because the gap is not temporary: it has persisted for several years since it first emerged in the mid-2000s and is expected to continue for years into the future. As developed countries share similar characteristics in terms of other factors of production, such as physical and human capital abundance, the energy endowment and price gap with the US may be an important source of comparative disadvantage for Europe.

In this paper, we investigate the impact of the persistent energy price gap between the US and Europe on the foreign direct investment decisions of firms. We use micro-data from the UK to investigate the incentives for individual firms that are heterogeneous in their energy intensity to operate production in the US and the EU. We also consider the decision to shut down energy intensive plants in the UK in response to the UK-US energy price gap. Our results provide evidence that the US FDI decisions by energy intensive UK firms have responded to the endowment-driven energy price gap. We find that this result is driven by the firm's most energy intensive line of production rather than its average energy intensity. Furthermore, there is evidence to suggest that the price gap is associated with an increased propensity for energy intensive plants owned by US investors to exit in the UK, relative to a control group of non-US investors. These results support the concern that US investors are relocating their energy intensive production from the UK.

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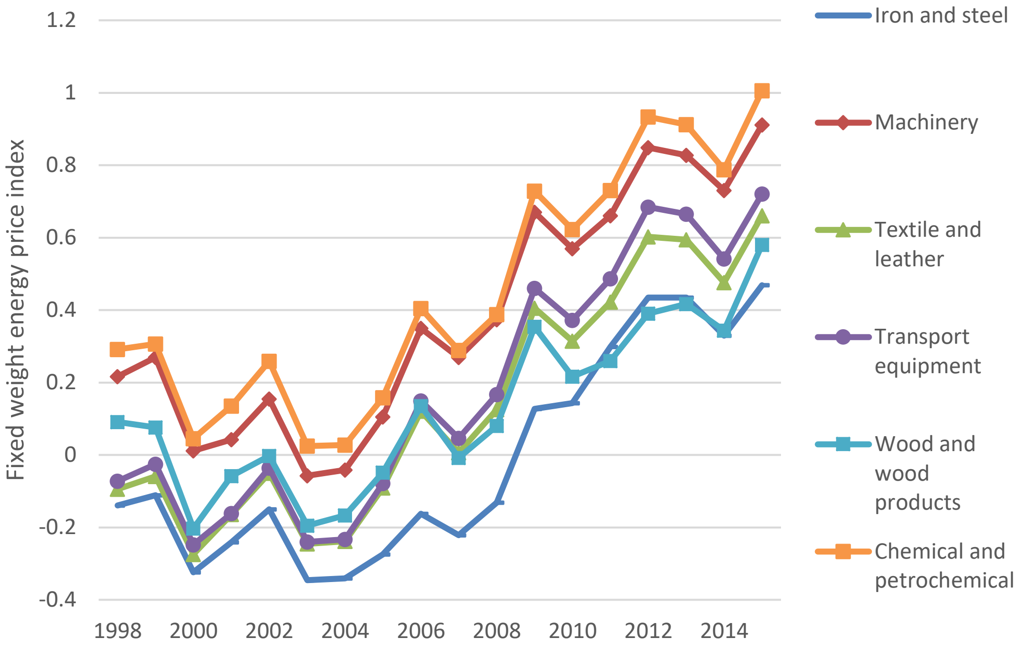
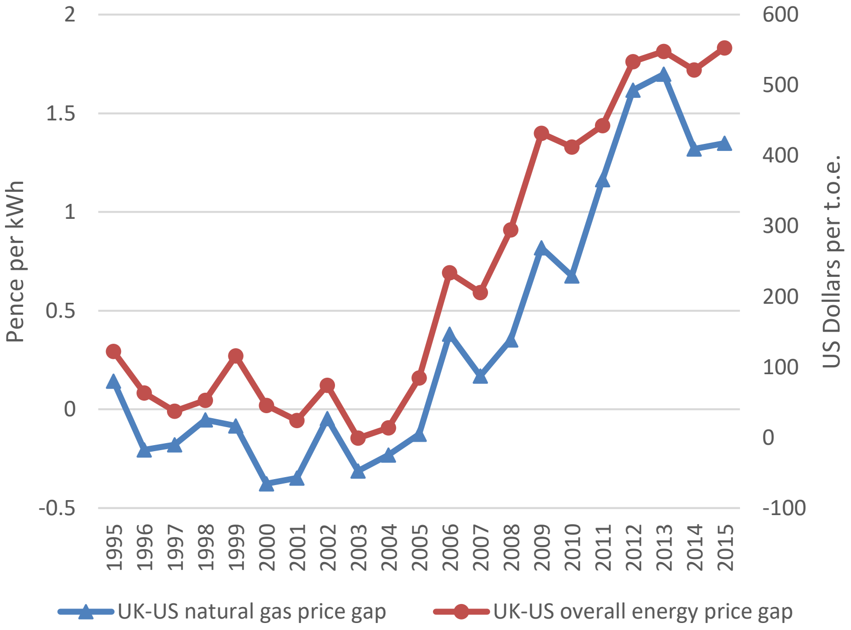
Appendix

Figure A1: Overall UK-US energy price gap for selection of manufacturing sectors



Notes: Figure shows the UK-US energy price gap in the fixed weight energy price index from Sato et al. (2018) using time-invariant weights from 2005.

Figure A2: UK-US natural gas price gap and overall energy price gap for manufacturing



Notes: The natural gas price gap is calculated using data on industrial sector natural gas prices from the IEA. The overall energy price gap is calculated using weighted average energy price data for four fuels (oil, natural gas, coal and electricity) for the manufacturing sector from Sato et al. (2018).

Table A1: Estimation of firm decision to enter into EU investment and exit from EU investment

	(1) OLS	(2) OLS	(3) PROBIT	(4) PROBIT
Panel A: Entry into EU				
ln(Energy Exp/Output)_k	0.003		0.003	
	(0.002)		(0.002)	
ln(Energy Exp/Costs)_k		0.002		0.002
		(0.002)		(0.002)
R^2	0.014	0.014	-	-
Pseudo R^2	-	-	0.0452	0.0436
Observations	5,936	5,936	5,936	5,936
Panel B: Exit from EU				
ln(Energy Exp/Output)_k	0.006		0.030	
	(0.041)		(0.031)	
ln(Energy Exp/Costs)_k		0.014		0.035
		(0.045)		(0.034)
R^2	0.105	0.105	-	-
Pseudo R^2	-	-	0.0248	0.0262
Observations	144	144	144	144
For all specifications:				
Energy Intensity	Max	Max	Max	Max
2-digit sector dummies	YES	YES	YES	YES

Notes: Levels regressions for the decision to enter into or exit from EU investment by 2015. Columns (1) and (2) estimate OLS regressions, where coefficients are reported with heteroskedasticity robust standard errors in parentheses. Columns (3) and (4) estimate probit regressions, where marginal effects are reported with standard errors in parentheses. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Table A2: First difference regressions for pre-sample US and EU investment over 1998 to 2006 long interval

	(1) ΔUSFDI	(2) ΔUSFDI	(3) ΔUSFDI	(4) ΔUSFDI	(5) ΔEUFDI	(6) ΔEUFDI	(7) ΔEUFDI	(8) ΔEUFDI
Panel A: Maximum Energy Intensity								
ln(Energy Exp/Output)_k	-0.002		-0.001		-0.001		-0.001	
	(0.001)		(0.001)		(0.001)		(0.002)	
ln(Energy Exp/Costs)_k		-0.002		-0.001		-0.002		-0.002
		(0.002)		(0.002)		(0.002)		(0.002)
R^2	0.000	0.000	0.009	0.009	0.000	0.000	0.002	0.002
Panel B: Overall Energy Intensity								
ln(Energy Exp/Output)_k	-0.001		-0.001		-0.001		-0.001	
	(0.002)		(0.002)		(0.001)		(0.001)	
ln(Energy Exp/Costs)_k		-0.001		-0.001		-0.002		-0.002
		(0.002)		(0.002)		(0.002)		(0.002)
R^2	0.000	0.001	0.009	0.009	0.000	0.000	0.002	0.002
For all specifications:								
Observations	7192	7192	7192	7192	7192	7192	7192	7192
2-digit sector dummies	NO	NO	YES	YES	NO	NO	YES	YES

Notes: First difference regressions for decision to invest in the US or EU for sampled firms. Table shows coefficients with heteroskedasticity robust standard errors in parentheses. Columns (1) to (4) consider the US investment decision while columns (5) to (8) consider the EU investment decision. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Table A3: Decision to invest in the US and EU over 2006 to 2015 long interval using energy intensity averaged over 2002-2005

	(1) ΔUSFDI	(2) ΔUSFDI	(3) ΔUSFDI	(4) ΔUSFDI	(5) ΔEUFDI	(6) ΔEUFDI	(7) ΔEUFDI	(8) ΔEUFDI
Panel A: Maximum Energy Intensity								
ln(Energy Exp/Output)_k	0.005***		0.006***		0.003		0.003	
	(0.002)		(0.002)		(0.002)		(0.002)	
ln(Energy Exp/Costs)_k		0.004*		0.006***		0.002		0.002
		(0.002)		(0.002)		(0.002)		(0.003)
R^2	0.001	0.001	0.010	0.010	0.000	0.000	0.009	0.008
Panel B: Overall Energy Intensity								
ln(Energy Exp/Output)_k	0.002		0.003		0.001		0.001	
	(0.002)		(0.002)		(0.002)		(0.002)	
ln(Energy Exp/Costs)_k		0.000		0.001		-0.001		-0.001
		(0.002)		(0.002)		(0.002)		(0.003)
R^2	0.000	0.000	0.009	0.009	0.000	0.000	0.008	0.008
For all specifications:								
Observations	5,887	5,887	5,887	5,887	5,887	5,887	5,887	5,887
2-digit sector dummies	NO	NO	YES	YES	NO	NO	YES	YES

Notes: First difference regressions for decision to invest in the US or EU for sampled firms using energy intensity averaged over 2002-2005. Table shows coefficients with heteroskedasticity robust standard errors in parentheses. Columns (1) to (4) consider the US investment decision while columns (5) to (8) consider the EU investment decision. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Table A4: First differences regressions for decision to invest in the US over 2006 to 2015 long interval controlling for time-varying effects of other factor intensities

	(1) ΔUSFDI	(2) ΔUSFDI	(3) ΔUSFDI	(4) ΔUSFDI	(5) ΔUSFDI	(6) ΔUSFDI	(7) ΔUSFDI	(8) ΔUSFDI
ln(Energy Exp/Output)_k	0.007***		0.006***		0.007***		0.006***	
	(0.002)		(0.002)		(0.002)		(0.002)	
ln(Capital Stock/Output)_k			0.003*				0.003*	
			(0.002)				(0.001)	
ln(Wages/Output)_k					0.000		0.000	
					(0.002)		(0.002)	
ln(Energy Exp/Costs)_k		0.008***		0.008***		0.009***		0.008***
		(0.002)		(0.002)		(0.003)		(0.003)
ln(Capital Stock/Costs)_k				0.003*				0.003*
				(0.002)				(0.002)
ln(Wages/Costs)_k						0.001		0.001
						(0.002)		(0.002)
Observations	5771	5771	5771	5771	5771	5771	5771	5771
R^2	0.011	0.012	0.012	0.012	0.011	0.012	0.012	0.012
2-digit sector dummies	YES	YES	YES	YES	YES	YES	YES	YES

Notes: First difference regressions for decision to invest in the US FDI for sampled firms. Table shows coefficients with heteroskedasticity robust standard errors in parentheses. Columns (1) and (2) repeat baseline results from Table 4. Columns (3) and (4) introduce capital intensity interaction term. Columns (5) and (6) introduce labour intensity interaction term. Columns (7) and (8) include all three interaction terms. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Table A5: Effect of firm energy intensity on the propensity to invest in the US and EU by year

	(1) US FDI	(2) US FDI	(3) EU FDI	(4) EU FDI
ln(Energy Exp/Costs)_k*2002_t	0.002	0.002	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
ln(Energy Exp/Costs)_k*2003_t	0.002	0.001	-0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
ln(Energy Exp/Costs)_k*2004_t	0.000	0.001	0.000	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)
ln(Energy Exp/Costs)_k*2005_t	0.001	0.001	0.000	0.002**
	(0.001)	(0.001)	(0.001)	(0.001)
ln(Energy Exp/Costs)_k*2006_t	-	-	-	-
ln(Energy Exp/Costs)_k*2007_t	0.001*	0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
ln(Energy Exp/Costs)_k*2008_t	0.000	-0.000	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)
ln(Energy Exp/Costs)_k*2009_t	-0.001	-0.000	-0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
ln(Energy Exp/Costs)_k*2010_t	-0.001	-0.001	-0.002	-0.001
	(0.001)	(0.001)	(0.002)	(0.002)
ln(Energy Exp/Costs)_k*2011_t	-0.001	-0.001	-0.002	-0.001
	(0.001)	(0.001)	(0.002)	(0.002)
ln(Energy Exp/Costs)_k*2012_t	0.000	-0.000	-0.001	-0.000
	(0.002)	(0.002)	(0.002)	(0.002)
ln(Energy Exp/Costs)_k*2013_t	0.002	0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
ln(Energy Exp/Costs)_k*2014_t	0.005***	0.003	0.000	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
ln(Energy Exp/Costs)_k*2015_t	0.006***	0.003	0.000	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)
Observations	137829	137829	137829	137829
R^2	0.801	0.801	0.749	0.749
Energy Intensity	Max	Overall	Max	Overall
Firm FEs	YES	YES	YES	YES
2-digit sector-year dummies	YES	YES	YES	YES

Notes: Fixed effects regressions for decision to invest in the US or EU for sampled firms using annual data over 2002-2015. Table shows coefficients with standard errors clustered at the firm level in parentheses. Columns (1) to (2) consider the US investment decision while columns (3) to (4) consider the EU investment decision. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Table A6: Plant exit in UK in response to overall energy price gap between the US and UK over 2002-2014

	(1) Cloglog	(2) OLS	(3) Firm FEs	(4) Firm FEs	(5) Firm FEs	(6) Firm FEs
ln(Employment)_pt	-0.312***	-0.027***	-0.038***	-0.037***	-0.037***	-0.036***
	(0.020)	(0.002)	(0.003)	(0.003)	(0.003)	(0.004)
ln(Productivity)_pt	-0.157***	-0.015***	-0.021***	-0.020***	-0.020***	-0.021***
	(0.027)	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
Multi_Ind_pt	0.333***	0.026***	0.036***	0.039***	0.040***	0.041***
	(0.059)	(0.005)	(0.010)	(0.008)	(0.009)	(0.009)
Multi_Man_kt	0.281***	0.022***	0.016***	0.016***	0.014***	0.014***
	(0.051)	(0.004)	(0.005)	(0.005)	(0.005)	(0.004)
PriceGap_st	-1.562**	-0.028*	-0.007	0.511**		
	(0.661)	(0.015)	(0.015)	(0.250)		
PriceGap_st*ln(Energyintensity)_j	0.229	0.020	-0.032	-0.039*		
	(0.274)	(0.023)	(0.021)	(0.022)		
USFDI_kt	-0.115	-0.014*	-0.018**	-0.008	-0.010	-0.011
	(0.083)	(0.007)	(0.009)	(0.010)	(0.011)	(0.011)
USFDI_kt*ln(Energyintensity)_j	-0.264**	-0.032***	-0.040***	-0.044***	-0.053***	-0.052***
	(0.121)	(0.012)	(0.012)	(0.012)	(0.014)	(0.012)
USFDI_kt*PriceGap_st	0.092	0.013	0.017	0.008	0.018	0.019
	(0.222)	(0.017)	(0.019)	(0.017)	(0.018)	(0.014)
USFDI_kt*PriceGap_st*ln(Energyintensity)_j	-0.008	0.013	0.065**	0.067***	0.087***	0.081***
	(0.318)	(0.026)	(0.026)	(0.023)	(0.025)	(0.019)
Observations	48101	48101	48101	48101	47818	56903
R^2	-	0.049	0.144	0.154	0.201	0.184
Number of 5 digit industries	240	240	240	240	240	263
Region fixed effects	YES	YES	YES	YES	YES	YES
5 digit industry effects	YES	YES	YES	YES	NO	NO
Year fixed effects	YES	YES	YES	NO	NO	NO
Firm fixed effects	NO	NO	YES	YES	YES	YES
2 digit sector-year effects	NO	NO	NO	YES	NO	NO
5 digit industry-year effects	NO	NO	NO	NO	YES	YES
Foreign owned firms in sample	NO	NO	NO	NO	NO	YES

Notes: Table shows estimated coefficients with standard errors clustered at 5 digit industry level in parentheses. The specifications have a binary dependent variable that is equal to 1 in year t if t is the final year the plant is observed. All regressions control for a fully non-parametric baseline hazard function (plant survival spell effects). * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.

Table A7: Energy intensity in UK in response to energy price gap between the US and UK over 2002-2015

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(Employment)_rt	-0.093**	-0.103**	-0.050	-0.056	-0.092**	-0.103**	-0.050	-0.056
	(0.044)	(0.044)	(0.043)	(0.043)	(0.044)	(0.044)	(0.043)	(0.043)
ln(Productivity)_rt	-0.333***	-0.356***	-0.150***	-0.165***	-0.332***	-0.355***	-0.149***	-0.165***
	(0.053)	(0.054)	(0.041)	(0.043)	(0.053)	(0.054)	(0.041)	(0.043)
Multi_Ind_rt	0.005	0.012	0.016	0.024	0.004	0.012	0.014	0.024
	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)	(0.029)
Multi_Man_kt	-0.070**	-0.073**	-0.069**	-0.071**	-0.071**	-0.073**	-0.070**	-0.071**
	(0.034)	(0.029)	(0.034)	(0.030)	(0.034)	(0.029)	(0.035)	(0.030)
USFDI_kt	-0.015	-0.005	-0.003	0.006	-0.019	-0.013	-0.004	0.002
	(0.027)	(0.028)	(0.026)	(0.027)	(0.032)	(0.032)	(0.031)	(0.030)
USFDI_kt*PriceGap_t	0.040	0.053	0.023	0.035				
	(0.033)	(0.034)	(0.031)	(0.033)				
PriceGap_st					0.174		0.229	
					(0.288)		(0.283)	
USFDI_kt*PriceGap_st					0.058	0.086	0.024	0.052
					(0.063)	(0.066)	(0.061)	(0.062)
Observations	9332	9332	9332	9332	9332	9332	9332	9332
R^2	0.066	0.144	0.054	0.143	0.066	0.144	0.054	0.143
Year fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Reporting unit fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
2 digit sector-year effects	NO	YES	NO	YES	NO	YES	NO	YES

Notes: Table shows coefficients from within-reporting unit regressions with standard errors clustered at the reporting unit level in parentheses. Dependent variable is logged energy intensity of reporting unit r in time period t. Energy intensity is defined as a share of output in columns (1), (2), (5) and (6) and as a share of costs in columns (3), (4), (7) and (8). Columns (1) to (4) use the natural gas price gap, and columns (5) to (8) use the overall energy price gap. * indicates $p < 0.10$, ** indicates $p < 0.05$, and *** indicates $p < 0.01$.