Centre for Energy Economics Research and Policy

Evaluating the Impact of Brexit on Natural Gas Trade between the UK and the EU:

A Spatial Equilibrium Analysis

Yakubu Abdul-Salam

Email: y.abdul-salam@hw.ac.uk

CEERP Working Paper No. 8
May 2019

Heriot-Watt University
Edinburgh, Scotland
EH14 4AS
ceerp.hw.ac.uk

ABSTRACT

The United Kingdom (UK) and the European Union (EU) engage in significant natural gas trade through the Internal Energy Market (IEM). As the UK exits from the EU however, it is likely to also exit from the IEM given the seemingly intractable positions of both parties. Exit of the UK from the IEM would likely cause an increase in natural gas trade costs between the two. The increased trade costs result from a number of channels including (1) loss in trade efficiency arising from loss of EU financing previously aimed at improving efficiencies in trade between the two; (2) loss in trade efficiency arising from loss in the sophistication of financial instruments that are linked to the UK's membership of the EU and the IEM; (3) rising costs of doing business in the UK for many EU energy companies due to the effects of possible regulatory divergence between the UK and the EU; etc. We use a spatial equilibrium model to examine the trade flow, price and welfare implications of these cost effects on global natural gas trade, with a focus on the UK and the EU. We find that cost increases in the UK-EU natural gas trade links would result significant trade flow changes, with the UK and the EU reducing overall exports and increasing internal trade. As a result, there would be significant underutilisation of existing pipelines linking both parties. The Republic of Ireland would also form a significant number of new trade links to compensate for its reduction in imports from the UK. Total welfare losses in the UK and the EU are in the order of $479million and $602million respectively, which is equivalent to about 3.69% and 0.59% of the total value of natural gas trade for the respective parties in 2017. In the UK, the producer welfare loss is significantly higher, highlighting the vulnerability of the UK natural gas industry to cost increases in trade with the EU.

Keywords: Brexit; Natural gas; Trade; Spatial equilibrium; Welfare

1 INTRODUCTION

Natural gas is a critical globally traded energy commodity. It is a significant source of primary energy and constitutes close to a quarter (i.e. 23.35%) of global primary energy consumption, with this share expected to rise over the coming decades (BP Statistical Review of World Energy, 2017). In 2017, global natural gas consumption and production increased to the fastest rates since the immediate aftermath of the financial crises of the last decade. Natural gas is composed of methane (CH_4) but can also have proportions of other gases such as ethane, propane, pentane and nitrogen. It is used as a fuel in space heating, transport, industrial processes and electricity generation among other purposes. Relative to coal and oil, natural gas is a cleaner source of fuel as it emits lower amounts of pollutants such as carbon dioxide (CO_2), nitrogen oxide (NO_2), sulphur dioxide (SO_2) and particulates. With CO_2 emissions for example, natural gas emits only 56.1 tCO_2 per TJ while coal and oil emit 94.6 tCO_2 per TJ and 73.3 tCO_2 per TJ respectively. Also, the geological conditions necessary for hosting natural gas are less severe than for example oil, making it a more abundant and widespread fuel source (Rogner, 1989, Bhattacharyya, 2011). These factors partially explain the increasing preference for natural gas in primary energy consumption as the world transitions to cleaner energy in the wake of climate change concerns.

The United Kingdom (UK) and the European Union (EU) engage in significant natural gas trade. On average, more than 99% of the UK's annual natural gas exports are destined to the EU market whilst about 9.5% of all EU gas exports are destined to the UK (BP Statistical

Review of World Energy, 2017). Much of this trade is executed via natural gas pipelines and interconnectors, four of which link the UK and the European mainland via the North and Irish seas. Currently, trade in natural gas between the UK and the EU occurs under the rules of the Internal Energy Market (IEM), an institution established under Article 194 of the EU Treaty. The IEM aims to increase efficiency and promote competition in natural gas (and electricity) trade between EU member countries thereby reducing prices and costs, enhancing consumer and producer welfare, achieving greater market integration, etc. It is regulated by a complex system of rules and institutions that streamline and integrate the interface between EU national gas markets; and jointly optimises gas trade between them hence representing a first-best solution for trade. As an EU member country, the UK played a leading role in the design and function of the IEM. As it exits from the EU in 2019 however, there is significant likelihood that the UK would also exit from the IEM due to fundamentally divergent and incompatible differences in matters of principle between both parties. Specifically, the UK seeks to absolve itself of European trade rules which infringe on its post-Brexit sovereignty. On the other hand, the EU is a rules-based system and it is unlikely that it would allow the UK to fully participate and benefit from the IEM without compliance to its core trading rules.

If the UK opts out of the IEM, there would be significant long-term efficiency losses in natural gas trade between the UK and the EU, resulting in potentially higher trading costs, lower trade volumes and higher prices (Fredriksson et al., 2017, The European Union Committee of the UK House of Lords, 2018). This may arise through a number of channels. First, as a member of the EU, the UK accesses substantial funding for capital-intensive but cost-reducing and efficiency-enhancing energy projects from the EU. Example EU institutions that provide this funding include the European Investment Bank (EIB), the European Fund for Strategic Investment (EFSI) and the Connecting Europe Facility (CEF). Several of the projects funded by these EU institutions aim to enhance market integration between the UK and the EU. After Brexit and the UK's potential withdrawal from the IEM, access to these funds may be limited or discontinued hence projects aiming to facilitate and integrate UK and EU gas markets may suffer. This would have long term higher cost effects for trade between both parties. Second, the sophistication of trading arrangements via contracts and financial instruments between the UK and EU gas markets may reduce. As a result, trade gains between both parties arising from these arrangements might diminish which may then manifest in higher trading costs. Third, the Republic of Ireland which is an EU member country imports a high share of its natural gas consumption from the UK. From an energy security perspective therefore, the EU through the Republic of Ireland is indirectly but significantly exposed to the UK in respect of its security of gas supply. This may have cost-increasing effects on trade between the UK and the EU via the Republic of Ireland.

Fourth, many EU national gas and energy utility companies are significantly active in the UK. Exit of the UK from the IEM would expose these companies to regulatory risk as the UK and the EU choose potentially divergent future regulations, laws and policies for natural gas markets. This would lead to higher natural gas trading costs for these businesses, especially those businesses exposed to sourcing natural gas via the UK-EU trade links. Protectionist policies and laws may also be effected by the UK and the EU, which would exacerbate this cost-effect. Fifth, natural gas trade between the UK and the EU are currently tariff-free. However, tariffs may apply and possibly increase for supply of energy plant and materials trade between both parties thereby increasing the cost of trade between them. Finally, the UK's exit from the IEM may increase the risk of gas shortages for both parties during emergency and/or high demand periods. As the two parties are contemporaneously exposed to the same demand forces, trade may fall in high demand periods as both parties look to bolster natural gas supplies to meet own demand. An example such situation is during periods of extreme cold weather winters such as the 2009/10 and 2010/11 UK winters; or phenomena such as the 'Beast from the East' in 2018 which precipitated snow, high storms and plummeting temperatures thereby increasing gas demand significantly in the UK and parts of the EU. Bolstering own-supplies to enhance energy security in critical periods may have the effect of an implicit restriction on natural gas trade between the UK and the EU, leading to higher costs.

We develop a Spatial Equilibrium (SE) model to quantify the likely trade flow, price and welfare effects of potential cost increases in natural gas trade between the UK and the EU, highlighting the risks and opportunities that this may represent for both parties as well as other countries in global natural gas trade. We find that cost increases in the UK-EU natural gas trade links would result significant trade flow changes, with the UK and the EU reducing overall exports and increasing internal trade. As a result, there would be significant underutilisation of existing pipelines linking both parties, and negative implications for the economic feasibility of planned future pipelines connecting the two. The Republic of Ireland would also form a significant number of new trade links to compensate for its reduction in imports from the UK. The new trade links would be based on Liquefied Natural Gas (LNG) trade rather than pipeline trade. The Republic of Ireland which hitherto had heavily depended on pipeline imports from the UK would therefore need to invest in new infrastructure (e.g. regasification facilities) to allow for the new trade in LNG. Total welfare losses in the UK and the EU are in the order of \$479million and \$602million respectively, which is equivalent to about 3.69% and 0.59% of the total value of natural gas trade for the respective parties in 2017. In the UK, the loss in producer surplus is significantly higher, highlighting the vulnerability of the UK natural gas industry to cost increases in trade with the EU.

2 METHOD

2.1 MODEL STRUCTURE

We use a large-scale SE model to examine the trade flow, price and welfare effects of potential post-Brexit increases in natural gas trade costs between the UK and the EU. The SE model was introduced by Samuelson (1952) in a seminal paper, and was later popularised by Takayama and Judge in a series of papers (see e.g. Takayama and Judge, 1970, Takayama and Judge, 1971, Takayama and Judge, 1964). It has since been widely used by economists for trade policy analyses (see e.g. Devadoss et al., 2005, Stennes and Wilson, 2005, Bennett and Yuan, 2017, Jiang et al., 2017, Boyd et al., 1993, Adams and Haynes, 1980, Shei and Thompson, 1977, Guajardo and Elizondo, 2003). Hieu and Harrison (2011) and Devadoss (2013) conduct theory and application reviews of SE models. As the name suggests, the SE model is a spatially explicit model, where nodes in space representing countries or markets are separated by distances characterised by trade flows. It assumes perfect competition, and resolves arbitrage in trade between nodes so that net profit is zero.

As we are interested in examining the effects of trade costs in natural gas trade, we use the variant of the SE model specified in Takayama and Judge (1971) and Devadoss (2013) where ad-valorem tariffs are explicitly considered. We model increased UK-EU natural gas trade costs as an implicit marginal increase in ad-valorem tariffs in trade between the two. It is important to note that in the status quo of IEM trade, explicit ad-valorem tariffs in natural gas trade between the UK and the EU is zero. This is unlikely to change in the post-Brexit market, given the relationship and mutual interests of the two. However, we assume that the potential increases in natural gas trade costs through the channels outlined in Section 1 would have the effect of an implicit non-zero ad-valorem tariff cost, hence our use of the mentioned variant of the SE model to capture the consequences of these cost effects for trade flows, prices and welfare. Specifically, consider n countries, each of which has the following linear inverted supply and demand functions for natural gas;

$$p_i^S = \gamma_i + \eta_i \mathrm{Q}_i^S \;\; \forall \; i = 1, ..., n \tag{1}$$

$$p_i^D = \lambda_i - \omega_i \mathrm{Q}_i^D \;\; \forall \; i = 1, ..., n \tag{2}$$

where i is the set of countries; γ, η, λ and ω are function coefficients; Q_i^S and Q_i^D are natural gas quantities supplied and demanded respectively; and p_i^S and p_i^D are natural gas supply and demand prices respectively. Now consider $X_{i,j}$ and $T_{i,j}$ to be the trade flow quantity and the unit transportation cost of natural gas exported from country i to country j respectively; $\delta_{i,j}$ to be the percentage increase in trade costs between country i and country j ; and ρ_i^S and ρ_i^D to be the market supply and demand prices of natural gas respectively. Given the above notations and definitions, the primal form of the variant of the SE model that we use, characterised as a Mixed Complementarity Problem (MCP), is formulated as follows;

$$\sum_{j=1}^{n} X_{i,j} \le Q_i^S \;\; \forall \; i \tag{3}$$

$$\sum_{i=1}^{n} X_{i,j} \ge Q_j^D \;\; \forall \; j \tag{4}$$

$$p_i^S = \gamma_i + \eta_i \mathrm{Q}_i^S \ge \; \rho_i^S \;\; \forall \; i \tag{5}$$

$$p_i^D = \lambda_i - \omega_i \mathrm{Q}_i^D \le \; \rho_i^D \;\; \forall \; i \tag{6}$$

$$\left(1+\delta_{i,j}\right)\left(\rho_i^S + T_{i,j}\right) \ge \rho_j^D \;\; \forall \; i, j \tag{7}$$

$$Q_i^D \ge 0,\; Q_i^S \ge 0,\; X_{ij} > 0,\; \rho_i^D \ge 0,\; \rho_i^S \ge 0$$

Equation (3) is an excess supply constraint which stipulates that a country may not export more than it produces. Equation (4) is an excess demand constraint which stipulates that demand in each country must be met by the imports from all other countries. Equation (5) is an optimal supply constraint which stipulates that a country's supply price must be greater than or equal to the market supply price. Equation (6) is an optimal demand constraint which stipulates that a country's demand price must be less than or equal to the market demand price. Here it is important to distinguish between country prices (p) and market prices (ρ). For an interior solution at the optimum, the following conditions hold; $p_i^d = \rho_i^d$, and $p_i^s = \rho_i^s$ (Takayama and Judge, 1971, Devadoss et al., 2005). For corner solutions however, both prices may differ. Finally, equation (7) is a location equilibrium constraint which stipulates that the market supply price in export country i plus transportation costs adjusted for the percentage increase in trade costs $\delta_{i,j}$ is greater than or equal to the market demand price in import country j. Quantities of demand, supply, trade flows and prices are non-negative.

2.2 MODEL CALIBRATION

Typically, the base solution in SE model (3)-(7) for trade flow variable $X_{i,j}$ does not exactly replicate the real-world observed trade flow data, which we notate as $X_{i,j}^{data}$. Over-specialisation often occurs, wherefore the SE model base solution for trade flows variable $X_{i,j}$ is restricted to a subset of the real world observed trade flows data $X_{i,j}^{data}$. The SE model therefore has to be calibrated for variable $X_{i,j}$ to exactly replicate the observed trade flows data $X_{i,j}^{data}$ before the imposition of policy scenarios. To achieve this calibration, we use the Positive Mathematical Programming (PMP) approach (Howitt, 1995). This calibration approach is elegant in the sense that it helps achieve exact replication of the observed trade flows in the SE model without restraining the flexibility of the SE model itself (Heckelei, 2002). There are two steps involved in PMP calibration. In the first step a tautological constraint is augmented to the SE model to force the trade flow variable $X_{i,j}$ to exactly replicate the observed real world trade flows data $X_{i,j}^{data}$ as follows;

$$X_{i,j} = X_{i,j}^{data} \tag{8}$$

The above additional constraint helps uncover the effective or true unit transportation cost of trade between countries. Let $\theta_{i,j}$ represent the dual variable of constraint equation (8). The differential of the Lagrangian function of SE model (3)-(8) with respect to trade flows variable $X_{i,j}$ results a condition that is then used to specify the effective unit transportation cost $\hat{T}_{i,j}$ of trade between countries as follows;

$$\hat{T}_{i,j} = T_{i,j} + \theta_{i,j} \tag{9}$$

In the second step of the PMP calibration procedure, the effective unit transportation cost $\hat{T}_{i,j}$ is used instead of the nominal unit transportation cost $T_{i,j}$ to solve SE model (3)-(7) (i.e. this time without the calibration constraint equation (8)). As the effective transportation cost $\hat{T}_{i,j}$ reflects the true unit marginal cost of transportation from exporting country i to importing country j, exact replication of the observed trade flows data $X_{i,j}^{data}$ is achieved as the base solution for trade flow variable $X_{i,j}$. Once calibration is achieved, the SE model is used to simulate policy scenarios.

2.3 MODEL SOLUTION

Rutherford (2002) find that economic equilibrium models such as the SE model are more efficiently solved as MCPs. This advises our choice of the MCP formulation above, rather than the alternative non-linear programming (NLP) approach. The model is implemented in the

General Algebraic Modelling System (GAMS) software using the PATH solver. To simulate the effects of increased trade costs on trade flows, prices and welfare, we bi-directionally and equally adjust the parameter $\delta_{i,j}$ upwards for trade between the UK and the EU only (i.e. $\Delta\delta_{UK,EU} = \Delta\delta_{EU,UK}$). Producer and consumer surpluses (i.e. welfare) are calculated post-policy simulations as follows;

$$ps_i = 0.5 \times \left(Q^S_{i,final} + Q^S_{i,initial} \right) \times \left(p^S_{i,final} - p^S_{i,initial} \right) \tag{10}$$

$$cs_i = 0.5 \times \left(Q^D_{i,final} + Q^D_{i,initial} \right) \times \left(p^D_{i,initial} - p^D_{i,final} \right) \tag{11}$$

where ps_i and cs_i are respectively the producer and consumer surpluses of country i; initial quantities and prices reflect the base data whilst final quantities and prices reflect post simulation predictions. We impose additional constraints in the model to reflect the reality of global gas trade. In particular, we constrain the model from decreasing pipeline gas trade by more than 50%. This reflects the unlikelihood of pipelined trade links being severed completely as the infrastructure is cheaper and convenient, and would typically have been established through long term trade and transport contracts between parties so that the lumpy investment costs would be recovered. We also constrain smaller exporting countries from increasing existing export flows by more than 20% as these countries would likely not have the pre-existing infrastructure to achieve significantly increased exports in the short to medium term.

3 DATA

We use data from a series of sources to specify our global SE model. Our primary source of natural gas trade, consumption and production data is the BP Statistical Review of World Energy (2017). Where trade data from this source is unavailable, we augment with data from other sources such as the UN Comtrade (2018) and the ITC Trademap (2018). The extract of data that we use is summarised in Table 1, Figure 1 and Figure 2.

Table 1 shows the maximum annual gas trade flows between relevant countries and regions over the last decade of the data (i.e. 2007 – 2017). As ours is a static SE model, use of annual trade for a single year conceals the historical trade flows between countries and regions. For example, as shown in Figure 1a, total EU26 exports to the UK in 2017 is much lower than the historical trend suggests. Use of maximum annual gas trade flows over the last decade of the data as the basis of our base trade data for static SE modelling affords a better sense of the historical trade links that have existed between countries and regions in the recent past. Table 1 shows that the UK has exported a maximum annual amount of about 8,269 kilotonnes of natural gas to the EU26 over the last decade of data. This is more than it has exported to any other world country or region. Although an EU member country, we separately present the Republic of Ireland as a special case because of its high dependency on UK imports. In addition to exports to the EU26, the UK has exported a maximum annual amount of about 3,855 kilotonnes of natural gas to the Republic of Ireland, further highlighting the importance of the EU market for UK natural gas exports. These maximal UK exports occurred in 2009 and 2011 for the EU26 and the Republic of Ireland respectively, as shown in Figure 1a.

In the same time period, Table 1 shows that the EU26 have exported a maximum annual amount of about 7,764 kilotonnes of natural gas to the UK, with this flow occurring in 2013 as shown in Figure 1a. This is equivalent to the EU26's second highest exports to any other world region, with its exports to the Commonwealth of Independent States (CIS) only marginally higher. The UK however imports significantly more natural gas from non-EU Europe and the Middle East, with a maximum annual amount of about 26,235 kilotonnes and 15,983 kilotonnes (in 2017 and 2011) respectively from both regions. Similarly, the EU imports significantly more natural gas from other world regions such as the CIS (about 125,208 kilotonnes in 2017), non-EU Europe (about 68,512 kilotonnes in 2012) and Northern Africa (about 48,576 kilotonnes in 2008).

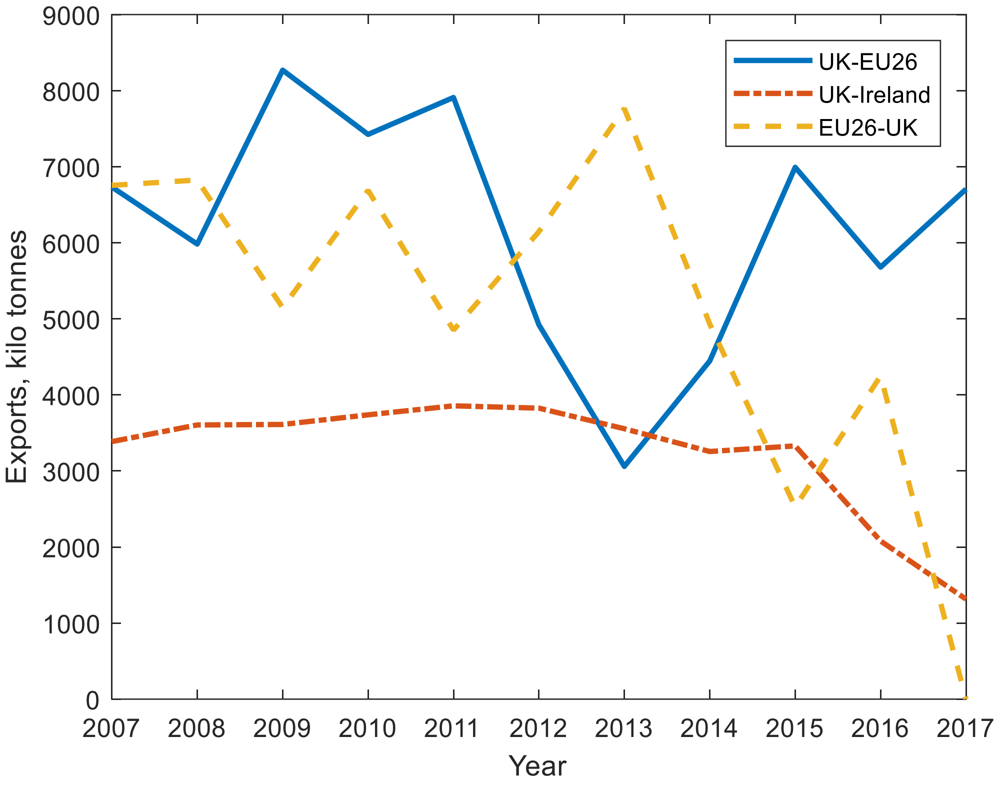
Table 1: Maximum annual natural gas trade in the period 2007 – 2017 for the UK, the EU, the Republic of Ireland and major world regions (kilotonnes). All countries included

From	**To**												
	Asia Pacific	CIS	Caribbean	EU26	Other Europe	Ireland	Middle East	North America	Northern Africa	South America	Southern Africa	UK	Western Africa
Asia Pacific	135,376.41	♦	♦	♦	♦	♦	1,106.31	1,443.04	404.32	130.33	♦	54.75	
CIS	40,634.50	76,037.10	♦	125,208.65	31,047.27	♦	9,153.43	♦	♦	♦	♦	3,280.90	
Caribbean	2,621.50		1,995.88	4,279.09	301.05		901.99	10,335.36	385.54	6,002.76		1,453.05	
EU26	3,155.42	10,671.48	92.27	57,021.37	2,085.61	♦	743.98	249.94	658.20	1,781.39	♦	7,764.82	4.53
Eastern Africa	♦	♦		♦	♦	♦	♦	♦	♦	♦	3,149.76	♦	
Other Europe	378.52	♦	♦	68,512.26	1,179.99	♦	183.03	718.38	209.89	691.52	♦	26,235.20	
Ireland												♦	
Middle Africa	4,322.79		67.91	469.61	210.21		1,648.87	386.22	207.68	1,033.95		♦	
Middle East	76,481.44	1,623.09	201.31	15,528.81	8,331.92	♦	18,335.53	5,748.80	4,978.06	1,590.84	♦	15,983.10	
North America	5,242.27	♦	175.79	1,374.57	491.31	♦	1,382.55	120,624.29	134.04	1,157.63	♦	104.67	
Northern Africa	5,731.57	♦	♦	48,576.32	3,499.19	♦	4,540.39	4,897.32	3,545.35	461.89	♦	1,698.89	
South America	1,528.81	♦	1.35	2,837.09	♦	♦	5.44	3,142.28	♦	14,322.21	♦	99.19	♦
Southern Africa	39.91												
UK	74.67	♦	29.43	8,269.32	137.54	3,855.73	133.66	♦	67.63	116.02	♦		
Western Africa	10,364.70		181.79	11,211.61	1,579.10		2,227.53	2,665.76	1,060.87	2,262.77		865.32	641.13

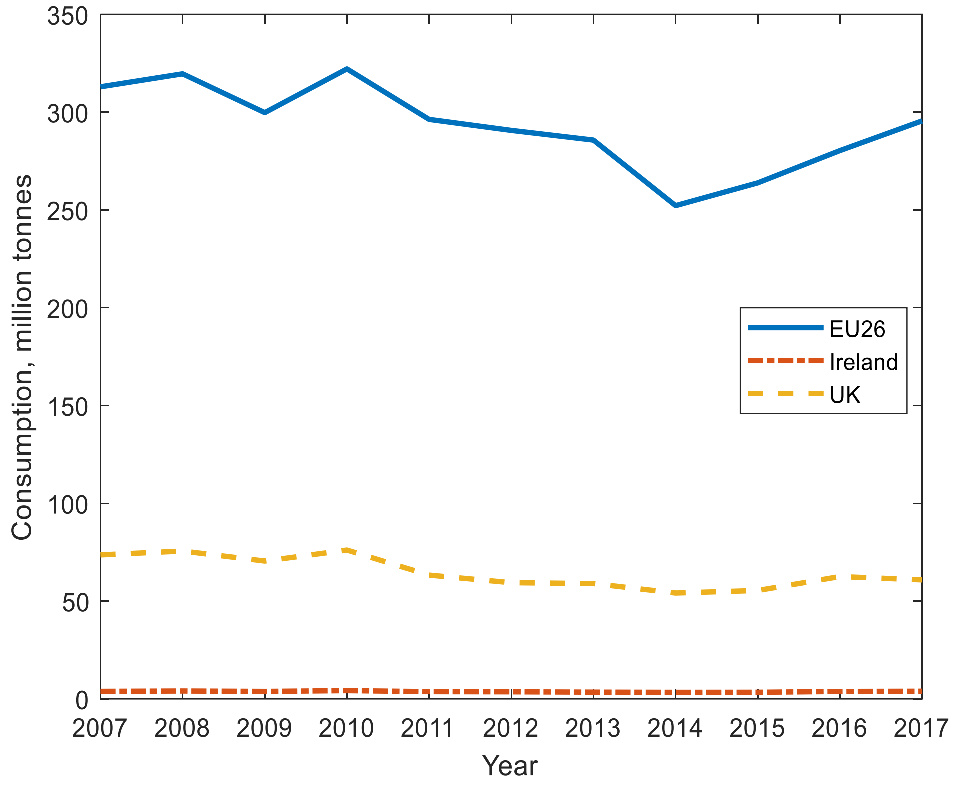
♦ Less than 0.01 kilotonnes
*BP Statistical Review of World Energy (2007 – 2017)
*EU26 excludes the UK and the Republic of Ireland
*Based on a conversion factor of 1 kilo tonne = 1.294585*10^{-3} Bcm for all countries

Despite the significant levels of natural gas trade between the UK and the EU however, historical trade between them as a proportion of their consumption levels is small. Figure1.b shows the EU26, UK and the Republic of Ireland consumption levels and trend over the last decade of the data. Figure 2.a shows that the UK's exports to the EU26 only forms a small proportion (about 2.21%) of the EU26's total consumption. Similarly, the EU26's exports to the UK only form a small proportion (about 8.63%) of the UK's total consumption. The Republic of Ireland however, an EU member country, is significantly dependent on UK natural gas imports for its consumption. Figure 2.b shows trade as a proportion of their production levels. Notice that UK exports to the EU as a proportion of its production was lowest in 2013 when the UK experienced extreme winter conditions. This lends credence to the allusion in this paper that a likely consequence of Brexit is that implicit trade restrictions are realised in emergency or high demand periods as both parties bolter own-supplies to meet own-demand, leading to higher natural gas costs.

FIGURE 1: TRADE AND CONSUMPTION



A: Total annual natural gas exports between the UK, the EU26 and the Republic of Ireland



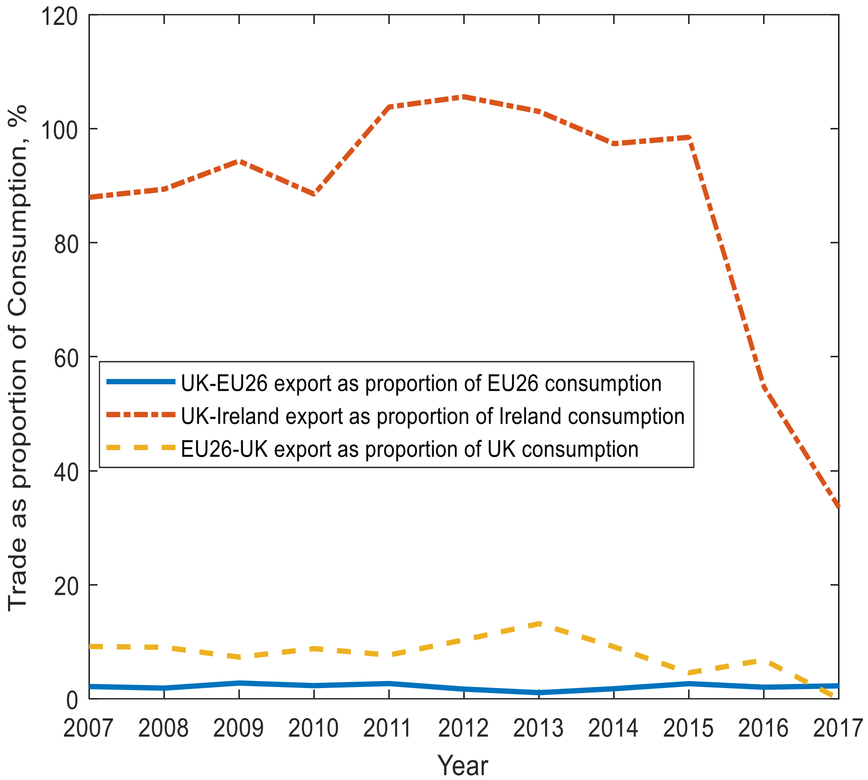
B: Total annual natural gas consumption in the UK, the EU26 and the Republic of Ireland

*BP Statistical Review of World Energy (2017)

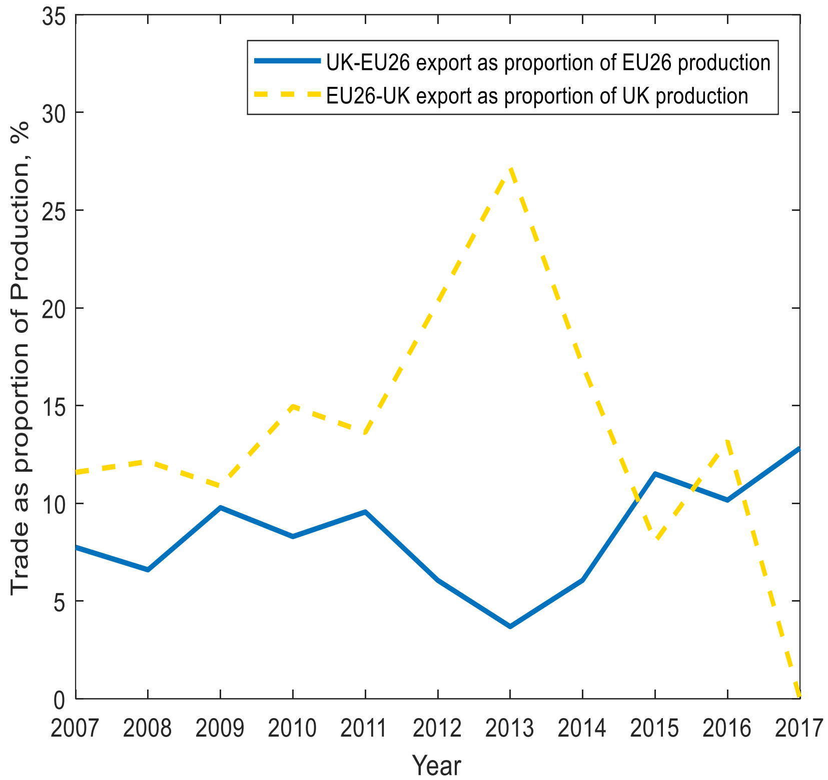
*EU26 excludes the UK and the Republic of Ireland

*Based on a conversion factor of 1 kilo tonne = 1.294585*10^{-3} Bcm for all countries

FIGURE 2: TRADE AS A PROPORTION OF CONSUMPTION AND PRODUCTION



A: Trade as a proportion of consumption in the UK, the Republic of Ireland and the EU26



B: Trade as a proportion of production in the UK and the EU26 (The Republic of Ireland production is small, hence not shown in the figure)

We require price and elasticity estimates to derive the inverted linear supply and demand functions for each country. Using UN Comtrade (2018) and ITC Trademap (2018) data, we are able to construct a country's cost-insurance-freight (CIF) import price and the free-on-board (FOB) export price of natural gas as the ratio of the total value of trade ($) to the total weight of trade (tonnes) (hence $/tonne). Where price data is unavailable for a country, we use the regional price average. We use the CIF import prices as proxy for natural gas demand price; and use the FOB export prices as proxy for natural gas supply price. A number of studies have estimated the own-price elasticities of natural gas and similar primary energy fuels such as crude oil (see e.g. Krichene, 2002, Burke and Yang, 2016, Brenton, 1997, Asche et al., 2008, Dilaver et al., 2014, Caldara et al., 2018). We assume the own-price elasticity of natural gas to be -0.14, and own-price elasticity of supply to be 0.10. These are within the reported ranges in the literature for natural gas and similar primary energy fuels. With the natural gas supply and demand prices as well as price elasticities determined, we are able to specify the parameters of the inverted linear supply and demand functions for each country.

Following Devadoss et al. (2005), we use the constructed CIF import prices and the FOB export prices of selected countries to calculate the transport cost of natural gas trade between all countries. Specifically, the unit transportation cost (in $/tonne) is calculated as the difference between the CIF import price and FOB export price of natural gas trade between the selected countries. This figure is then divided by the trade distance between the selected countries to get the unit transportation cost (in $/tonne.km), which is then assumed to be the same for trade between all countries. We use bilateral trade distance estimates provided by Mayer and Zignago (2011). For any two trading countries, these distances are estimated to account for closeness of trade ties, difficulty of access to markets, border effects, language effects, as well as the significance of the different modes of transport involved in trade (e.g. shipping, trucking, rail, etc.).

Finally, we need data on the prevailing ad-valorem tariff levels for natural gas trade between countries. The WTO's Tariff Analysis Online facility (WTO Tariff Online Facility, 2017) provides a comprehensive database of the ad-valorem tariffs on natural gas trade between countries. A number of ad-valorem tariff classifications determine the specific tariff level realised in trade between countries. For example, natural gas exporting countries that are members of the WTO realise the Most Favoured Nation (MFN) tariff rate set by an importing WTO member country. On the other hand, some WTO member countries may have Preferential Trade Agreements (PTA) with lower tariffs agreed bilaterally, in which case the MFN tariff rate is over-ridden in favour of PTA tariffs. We use the applicable tariff rate for trade between countries as the basis for specifying our SE model. As mentioned earlier, UK-EU explicit tariff levels for natural gas trade are currently zero and this is unlikely to change in the post-Brexit market. However, we assume that increased UK-EU trade costs through the channels mentioned in Section 1 will have the effect of an implicit marginal ad-valorem tariff, which enables use of the SE model to examine the potential implications of this effect.

In our final dataset, only countries for which we have the complete and satisfactory information for all parameters (i.e. prices, trade distances, elasticities of supply and demand, existing tariffs), and for which the linear supply and demand functions are well defined and scaled are considered. Our final dataset for modelling consists of 93 countries involved in global natural gas trade. The regional classifications of the individual countries as well as their associations with relevant trade organisations are shown in Table A1 in the Appendix.

4 RESULTS

The matrix of results from the 93 natural gas trading countries used in our SE model is too large to fully present in the paper. In the interest of space therefore, only select results are presented. In particular, we present results for increased trade costs of up to 5%, which expert opinion assumes is likely to be realised for the reasons mentioned in our introduction; and 10% which is the likely realisable maximum. Full and further results are available upon request.

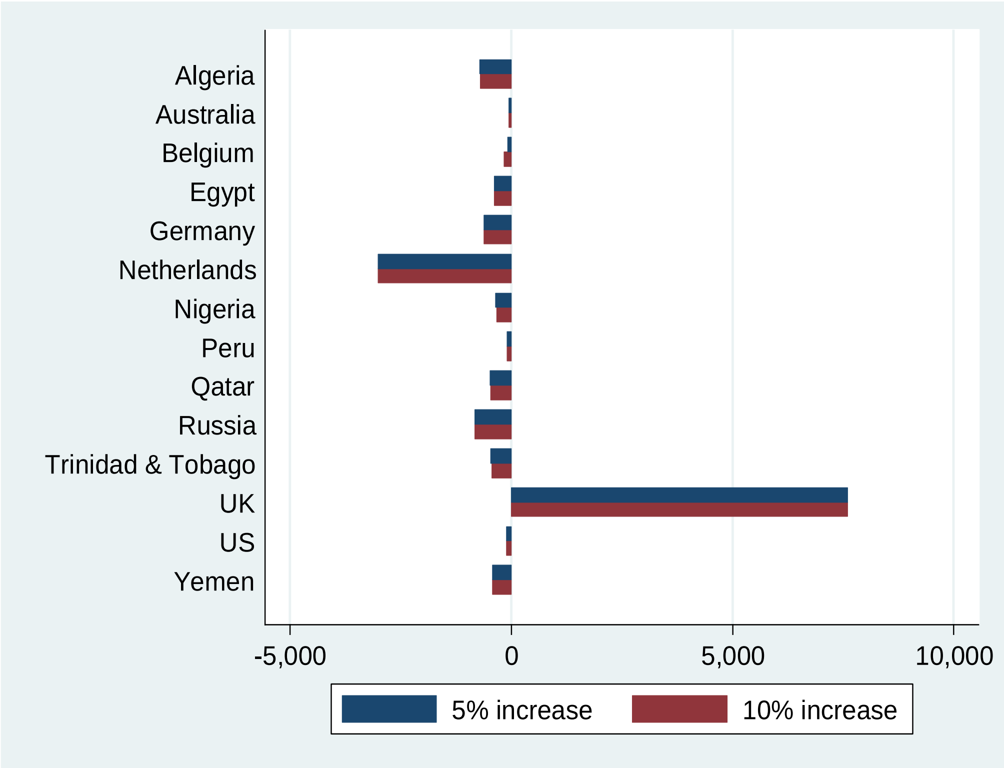
4.1 TRADE FLOW EFFECTS DUE TO INCREASED COST OF TRADE

Focusing on UK trade changes, Figure 3 shows a summary of the import and export trade changes with individual countries. The most significant change is the UK's resort to greater internal trade (i.e. a 10% increase in UK-UK trade) and its decrease in exports to the EU. The large increase in the UK's reliance on internal trade causes decreases in UK imports from the EU and other parts of the world, including Russia, Qatar and Algeria. As the UK-EU26 and the UK-Ireland trade are via pipeline, the decrease in trade from both directions would imply a significant underutilisation of the existing UK-EU pipeline capacity. This may also have negative implications for the economic feasibility of planned future expansions in pipeline connections for trade between both parties.

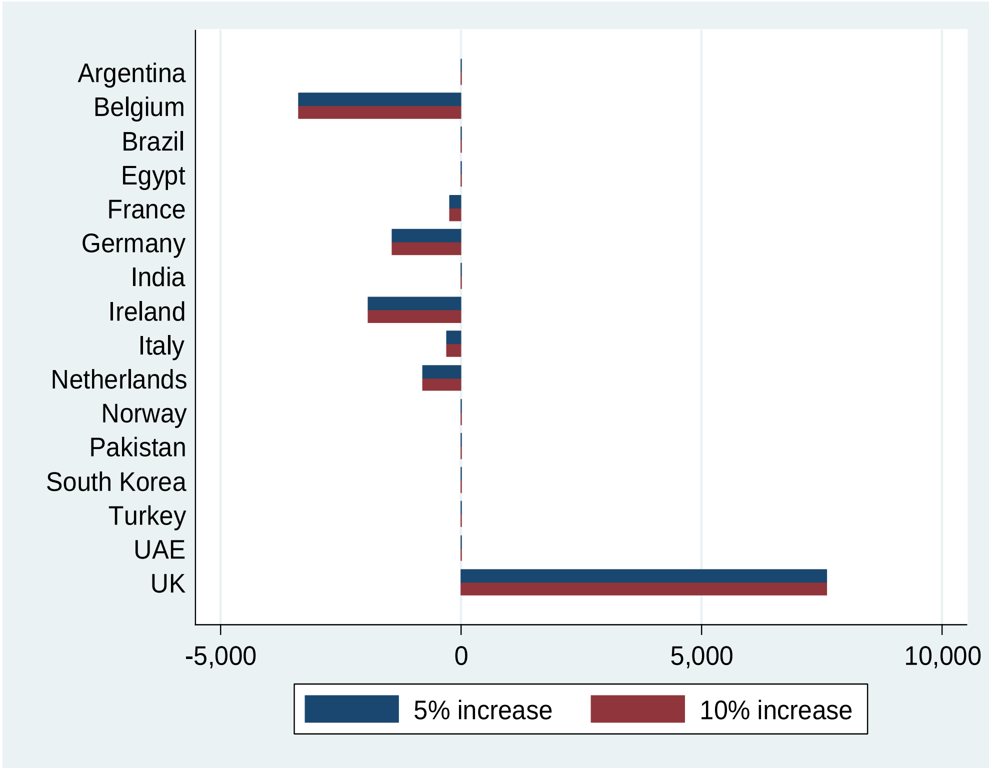
For the EU26, Figure 4 shows that there are increases in internal trade via the Netherlands and Germany; increased imports from other parts of the world including Qatar, Norway and Algeria; and decreased imports from in particular the UK, Russia and Egypt. Unlike the UK however, the EU26 increases exports to some countries including Argentina, Brazil and India. There is also increase in trade with the Republic of Ireland. Regarding the EU26's trade with the UK, the large decrease in EU26 imports and exports reflects the vulnerability of the existing trade to cost increases, and hence the importance of the IEM in keeping these costs down through inherent trading efficiencies.

For the Republic of Ireland, its large dependence on UK imports mean an increase in UK-EU trade costs causes a fundamental shift in its natural gas sourcing portfolio. Figure 5 shows that its imports from the UK decreases by half, with the remaining demand imported via new trade links with the EU (e.g. Germany and the Netherlands) and the rest of the world (e.g. US, Russia, Qatar, Norway and Algeria). As direct pipelines do not exist for trade between Ireland and these countries, these new trade links would imply a shift from gaseous gas via pipelines to LNG via shipping. A further implication also is that the Republic of Ireland would have to invest in infrastructure (e.g. regasification facilities) in the short to medium term to receive LNG gas imports from the EU and the rest of the world. Also, the decrease in the UK-Ireland trade link would have negative economic feasibility implications for planned pipeline expansions in the Irish Sea to facilitate trade between the two.

FIGURE 3: CHANGES IN UK IMPORTS AND EXPORTS AS A RESULT OF A 5% AND 10% INCREASE IN THE COST OF NATURAL GAS TRADE BETWEEN THE UK AND THE EU (KILOTONNES)

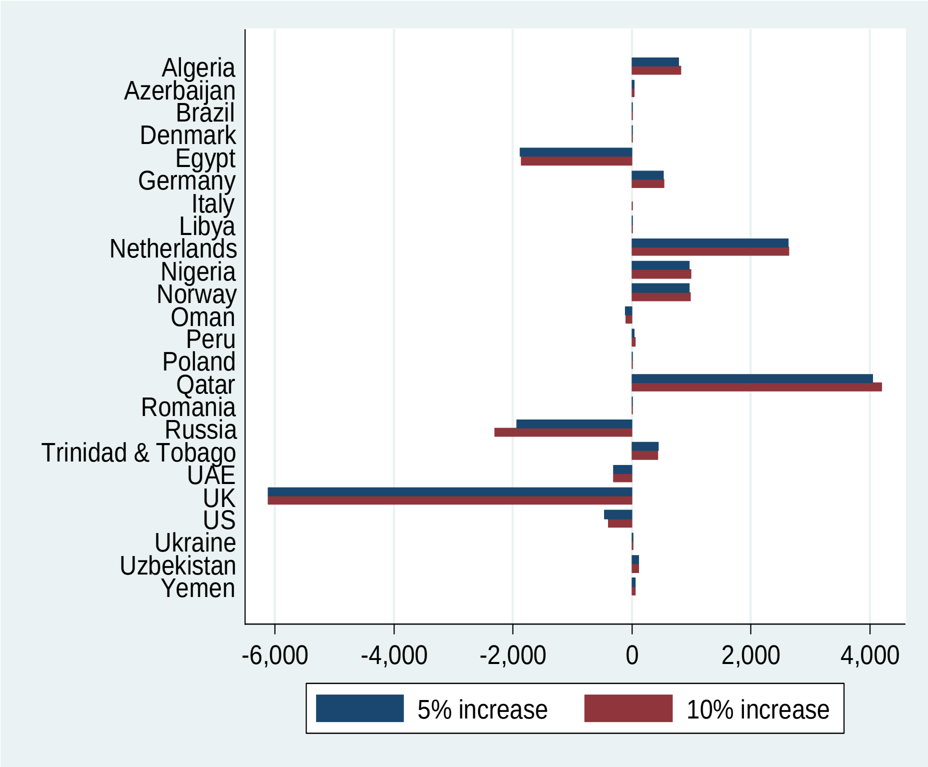


A. Changes in UK imports, kilotonnes

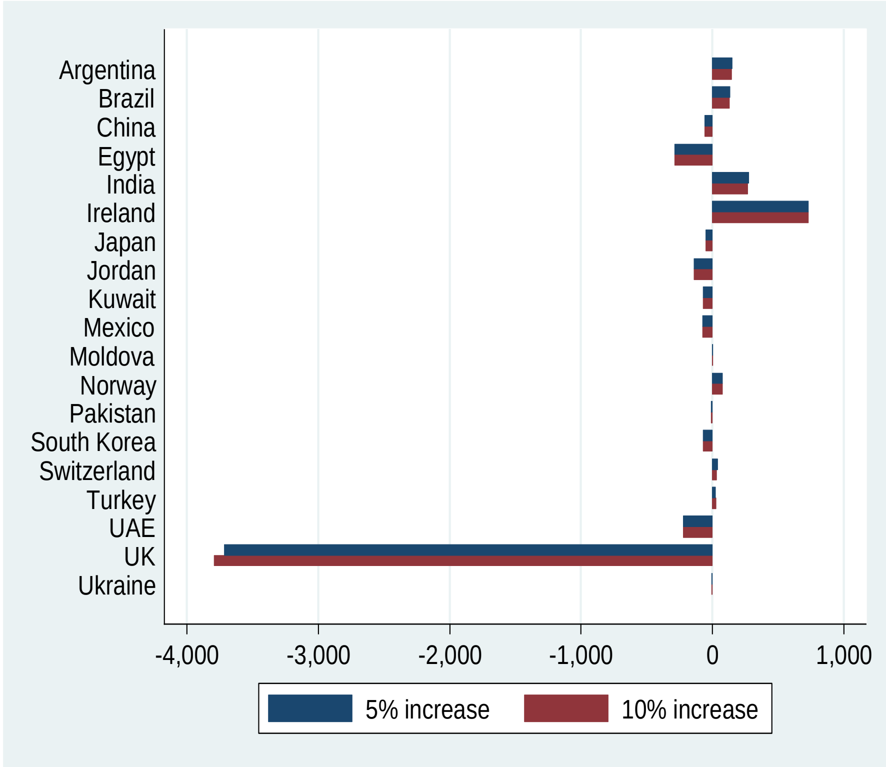


B. Changes in UK exports, kilotonnes

FIGURE 4: CHANGES IN EU26 IMPORTS AND EXPORTS AS A RESULT OF A 5% AND 10% INCREASE IN COST OF TRADE BETWEEN THE UK AND THE EU (KILOTONNES)



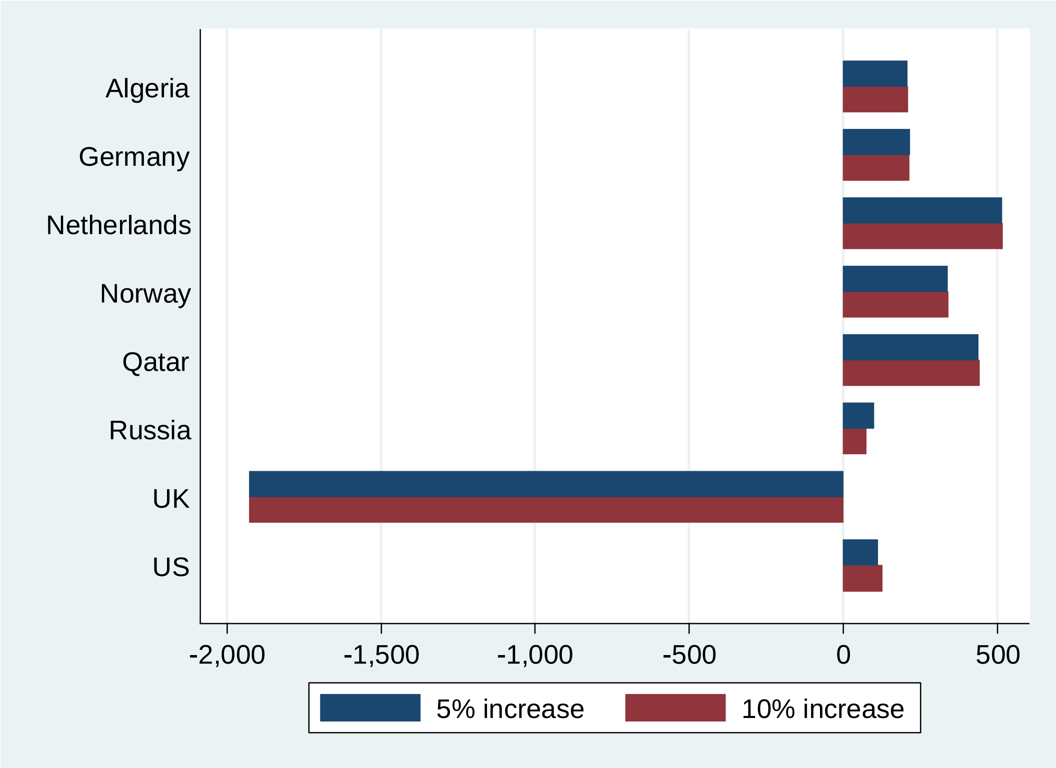
A. Changes in EU26 imports, kilotonnes



B. Changes in EU26 exports, kilotonnes

***EU26 EXCLUDES THE UK AND THE REPUBLIC OF IRELAND**

FIGURE 5: CHANGES IN IRELAND IMPORTS AS A RESULT OF A 5% AND 10% INCREASE IN COST OF TRADE BETWEEN THE UK AND THE EU (KILOTONNES)

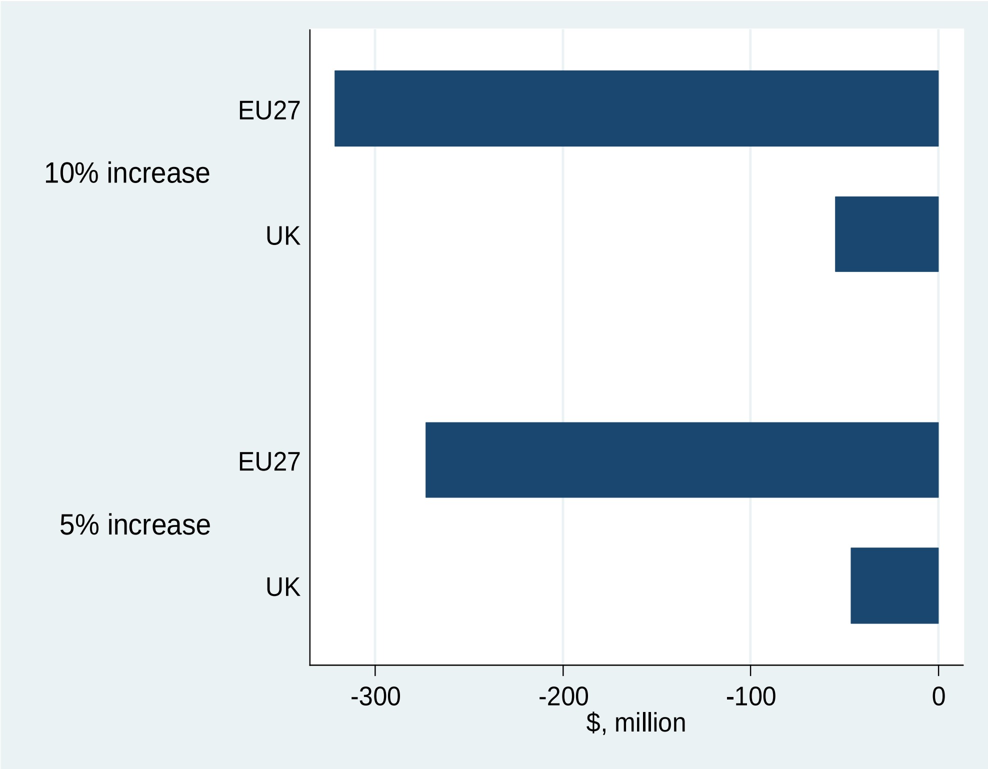


4.2 PRICES AND WELFARE

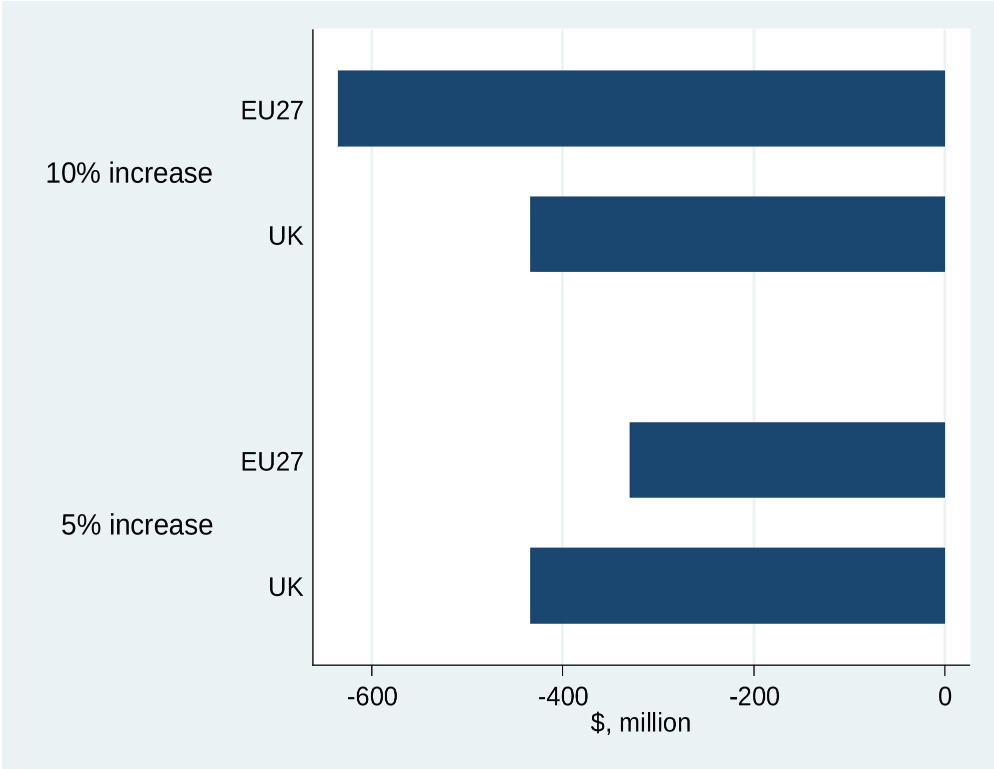
Figure 6 shows the loss in consumer and producer surpluses in the UK and the EU due to increased trade costs between the two. Price changes are less than 1% in all cases. The consumer surplus effect of the price changes are however significant. For the UK, loss in consumer surplus is in the order of $46million and $55million for 5% and 10% cost increases respectively. For Germany, loss in consumer surplus is in the order of $51million and $65million for 5% and 10% increased costs respectively. For the entire EU27, loss in consumer surplus is in the order of $272million and $321million for 5% and 10% cost increases respectively. Loss in producer surplus in the UK is in the order of $433million for a 5% and 10% cost increases. The high UK loss in producer surplus is expected, given that more than 99% of the UK's annual natural gas export is to the EU market. In the EU27, loss in producer surplus is in the order of $330million and $635million for 5% and 10% cost increases respectively. The loss in producer surpluses arise from the increased internal trade in the UK and the EU. The increased internal trade is inefficient, given that comparative advantage could be gained through trade at lower cost. The large relative loss of producer surplus in the UK reflects the loss in the advantage of the status quo, where over 99% of its annual natural gas exports are to the EU market.

At 5% cost increase, which we assume is the likely rate, the total welfare loss (i.e. loss in consumer and producer surpluses) for the UK and the EU are $479million and $602million respectively. Although the absolute welfare loss for the UK is less, the loss as a proportion of absolute value of natural gas trade is significantly higher for the UK than it is for the EU. For example, total natural gas trade for the UK and the EU in 2017 is about $12.99billion and $102.91billion respectively (UN Comtrade, 2018). Hence total welfare loss for the UK and the EU is about 3.69% and 0.59% of their respective total values of trade. For both parties also, there is differentiation in the share of the losses for producers and consumers. As a proportion of the total welfare loss, producers' share of the loss in the UK is larger than consumers' share. The opposite is true for the EU. This would imply that the burden of the welfare losses would be disproportionately borne by UK producers than it would be for EU producers. This has significant implications for the post-Brexit UK natural gas industry.

FIGURE 6: WELFARE CHANGES IN THE UK AND THE EU DUE TO INCREASED TRADE COSTS



A. Loss in consumer surplus ($, millions)



B. Loss in producer surplus ($, millions)

5 CONCLUSIONS

Natural gas is an important global primary energy commodity. The UK and the EU engage in significant natural gas trade. As the UK exits from the EU however, it is also likely to exit from the EU Internal Energy Market (IEM). The IEM is the EU institution established to regulate and maintain natural gas (and electricity) trade between EU member countries, with the goal to reduce trading barriers, enhance trade efficiency and reduce trade costs. With the UK's exit from the IEM, trading costs between the UK and the EU27 are likely to increase due to (1) loss in trade efficiency arising from loss of EU financing previously aimed at improving efficiencies in trade between the two; (2) loss in trade efficiency arising from loss in the sophistication of financial instruments that are linked to the UK's membership of the EU and the IEM; (3) energy security cost effects arising from the significant exposure of the Republic of Ireland (an EU member country) to UK gas imports; and (4) rising costs of doing business in the UK for many EU energy companies due to the effects of possible regulatory divergence between the UK and the EU; etc. We use a spatial equilibrium model to examine the trade flow, price and welfare implications of these cost effects on global natural gas trade, with a focus on the UK and the EU. The SE model assumes perfect competition and resolves arbitrage in trade between countries.

We find that cost increases in the UK-EU natural gas trade would result a significant re-alignment of UK natural gas trade, with an increased focus on internal trade. This would lead to significant welfare losses (overall welfare loss is $479million which is about 3.69% of UK trade value in 2017), with the producer welfare loss being significantly higher than consumer welfare loss. The high UK loss in producer surpluses is expected, given that more than 99% of the UK's annual natural gas exports are to the EU market. For the EU also, this would result significant trade changes. Internal trade would increase although to a lesser extent, whilst external trade through imports and exports are reconfigured. For the Republic of Ireland in particular, UK imports which it hitherto depended on heavily would be cut significantly. Remaining Irish demand would be sourced through new trade links with other countries, where the gas is imported via LNG rather than pipeline via the UK. Overall the EU27 would suffer high welfare losses too (overall loss is $602million which is about 0.59% of EU trade value in 2017), with the consumer welfare loss being significantly greater than producer welfare loss. The results show differentiation in the share of the welfare losses borne by consumers and producers in the UK and the EU, with greater imbalance in the UK where producers bear the greater share.

The overall decrease in UK and EU trade would result significant underutilisation of the existing pipeline links connecting the two, and would have negative economic feasibility implications for planned investments in future pipeline links. For the Republic of Ireland, the decreased UK trade would mean a shift from pipeline to LNG trade. This would have implications for short to medium term investments in regasification facilities and related infrastructure in order to allow for the shift to LNG trade.

In conclusion, our results give an indication of the likely trade, price and welfare implications of potential increases in costs in natural gas trade between the UK and the EU, as the UK exits the EU and the IEM. It is worth mentioning some limitations of our results however. In particular, the SE model used assumes perfect competition. Some research suggests that markets for primary energy products such as natural gas and oil may not be perfect. Also we have assumed feasible trade between all countries. There may be geopolitical reasons why trade within and between some countries and regions may not be feasible. These considerations have not been factored into our analysis. Further research may be needed to determine the possible post-Brexit implications of these considerations on UK-EU natural gas trade.

ACKNOWLEDGEMENT

The author would like to thank BP Plc, which supports his post-doctoral fellowship under the Centre for Energy Economics Research and Policy at the Heriot-Watt University. All usual caveats apply.

REFERENCES

ADAMS, D. M. & HAYNES, R. W. 1980. The 1980 softwood timber assessment market model: structure, projections, and policy simulations. *Forest Science,* 26**,** a0001-z0001.

ASCHE, F., NILSEN, O. B. & TVETERÅS, R. 2008. Natural gas demand in the European household sector. *The Energy Journal***,** 27-46.

BENNETT, M. & YUAN, Y. 2017. On the Price Spread of Benchmark Crude Oils: A Spatial Price Equilibrium Model.

BHATTACHARYYA, S. C. 2011. *Energy economics: concepts, issues, markets and governance,* Springer Science & Business Media.

BOYD, R., DOROODIAN, K. & ABDUL-LATIF, S. 1993. The effects of tariff removals on the North American lumber trade. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie,* 41**,** 311-328.

BP STATISTICAL REVIEW OF WORLD ENERGY. 2017. *BP Statistical Review of World Energy* [Online]. Available: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf [Accessed July 2018].

BRENTON, P. 1997. Estimates of the demand for energy using cross-country consumption data. *Applied Economics,* 29**,** 851-859.

BURKE, P. J. & YANG, H. 2016. The price and income elasticities of natural gas demand: International evidence. *Energy Economics,* 59**,** 466-474.

CALDARA, D., CAVALLO, M. & IACOVIELLO, M. 2018. Oil price elasticities and oil price fluctuations. *Journal of Monetary Economics*.

DEVADOSS, S. 2013. Ad valorem tariff and spatial equilibrium models. *Applied Economics,* 45**,** 3378-3386.

DEVADOSS, S., AGUIAR, A. H., SHOOK, S. R. & ARAJI, J. 2005. A spatial equilibrium analysis of US–Canadian disputes on the world softwood lumber market. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie,* 53**,** 177-192.

DILAVER, Ö., DILAVER, Z. & HUNT, L. C. 2014. What drives natural gas consumption in Europe? Analysis and projections. *Journal of Natural Gas Science and Engineering,* 19**,** 125-136.

FREDRIKSSON, G., ROTH, A., TAGLIAPIETRA, S. & ZACHMANN, G. 2017. The Impact of Brexit on the EU Energy System. *IP/A/ITRE/2017-01.* EU Directorate General for Internal Policies: EU.

GUAJARDO, R. G. & ELIZONDO, H. A. 2003. North American tomato market: A spatial equilibrium perspective. *Applied economics,* 35**,** 315-322.

HECKELEI, T. 2002. Calibration and estimation of programming models for agricultural supply analysis. *University of Bonn,* 159.

HIEU, P. S. & HARRISON, S. 2011. A review of the formulation and application of the spatial equilibrium models to analyze policy. *Journal of forestry research,* 22**,** 671.

HOWITT, R. E. 1995. Positive mathematical programming. *American journal of agricultural economics,* 77**,** 329-342.

ITC TRADEMAP. 2018. *ITC Trademap Database* [Online]. ITC Trademap: ITC Trademap. Available: https://www.trademap.org/# [Accessed July 2018].
JIANG, W., SEARLE, S. & SIDDIQUI, S. 2017. Analysis of the global wood-chip trade's response to renewable energy policies using a spatial price equilibrium model. *Biofuels, Bioproducts and Biorefining,* 11**,** 505-520.
KRICHENE, N. 2002. World crude oil and natural gas: a demand and supply model. *Energy economics,* 24**,** 557-576.
MAYER, T. & ZIGNAGO, S. 2011. *Notes on CEPII's distances measures: The GeoDist database* [Online]. Available: http://www.cepii.fr/PDF_PUB/wp/2011/wp2011-25.pdf [Accessed June 2018].
ROGNER, H.-H. 1989. Natural gas as the fuel for the future. *Annual review of energy,* 14**,** 47-73.
RUTHERFORD, T. F. 2002. Mixed Complementarity Programming with GAMS. *Lecture Notes for Econ*, 6433.
SAMUELSON, P. A. 1952. Spatial price equilibrium and linear programming. *The American economic review,* 42**,** 283-303.
SHEI, S.-Y. & THOMPSON, R. L. 1977. The impact of trade restrictions on price stability in the world wheat market. *American Journal of Agricultural Economics,* 59**,** 628-638.
STENNES, B. & WILSON, B. 2005. An analysis of lumber trade restrictions in North America: application of a spatial equilibrium model. *Forest Policy and Economics,* 7**,** 297-308.
TAKAYAMA, T. & JUDGE, G. 1970. Alternative spatial equilibrium models. *Journal of Regional Science,* 10**,** 1-12.
TAKAYAMA, T. & JUDGE, G. 1971. Spatial and Temporal Price and Equilibrium Models. *Amsterdam, North*.
TAKAYAMA, T. & JUDGE, G. G. 1964. Equilibrium among spatially separated markets: A reformulation. *Econometrica: Journal of the Econometric Society***,** 510-524.
THE EUROPEAN UNION COMMITTEE OF THE UK HOUSE OF LORDS 2018. Brexit: Energy Security. House of Lords: UK House of Lords.
UN COMTRADE. 2018. *UN Comtrade Trade Database* [Online]. UN Comtrade: UN Comtrade. Available: https://comtrade.un.org/data/ [Accessed July 2018].
WTO TARIFF ONLINE FACILITY. 2017. *WTO Tariff Online Facility* [Online]. Available: https://tao.wto.org/ [Accessed July 2018].

APPENDIX

Table A1: Final set of 93 countries in our data, their sub-regional placements and associations with relevant organisations

Sub-Region	Country	Associations			
		EU	**WTO**	**OECD**	**OPEC**
Asia Pacific	Australia	No	Yes	Yes	No
Asia Pacific	Brunei	No	Yes	No	No
Asia Pacific	China	No	Yes	No	No
Asia Pacific	India	No	Yes	No	No
Asia Pacific	Indonesia	No	Yes	No	No
Asia Pacific	Japan	No	Yes	Yes	No
Asia Pacific	Malaysia	No	Yes	No	No
Asia Pacific	Myanmar	No	Yes	No	No
Asia Pacific	Pakistan	No	Yes	No	No
Asia Pacific	Papua New Guinea	No	Yes	No	No
Asia Pacific	Singapore	No	Yes	No	No
Asia Pacific	South Korea	No	No	Yes	No
Asia Pacific	Taiwan	No	Yes	No	No
Asia Pacific	Thailand	No	Yes	No	No
CIS	Armenia	No	Yes	No	No
CIS	Azerbaijan	No	No	No	No
CIS	Belarus	No	No	No	No
CIS	Kazakhstan	No	Yes	No	No
CIS	Kyrgyzstan	No	Yes	No	No
CIS	Moldova	No	Yes	No	No
CIS	Russia	No	Yes	No	No
CIS	Tajikistan	No	Yes	No	No
CIS	Turkmenistan	No	No	No	No
CIS	Ukraine	No	Yes	No	No
CIS	Uzbekistan	No	No	No	No
Caribbean	Barbados	No	Yes	No	No
Caribbean	Dominican Republic	No	Yes	No	No
Caribbean	Jamaica	No	Yes	No	No
Caribbean	Trinidad & Tobago	No	Yes	No	No
EU26	Austria	Yes	Yes	Yes	No
EU26	Belgium	Yes	Yes	Yes	No
EU26	Bulgaria	Yes	Yes	No	No
EU26	Croatia	Yes	Yes	No	No
EU26	Czech Republic	Yes	Yes	Yes	No
EU26	Denmark	Yes	Yes	Yes	No
EU26	Estonia	Yes	Yes	Yes	No
EU26	Finland	Yes	Yes	Yes	No
EU26	France	Yes	Yes	Yes	No
EU26	Germany	Yes	Yes	Yes	No

Sub-Region	Country	Associations			
		EU	WTO	OECD	OPEC
EU26	Greece	Yes	Yes	Yes	No
EU26	Hungary	Yes	Yes	Yes	No
EU26	Italy	Yes	Yes	Yes	No
EU26	Latvia	Yes	Yes	Yes	No
EU26	Lithuania	Yes	Yes	No	No
EU26	Luxembourg	Yes	Yes	Yes	No
EU26	Malta	Yes	Yes	No	No
EU26	Netherlands	Yes	Yes	Yes	No
EU26	Poland	Yes	Yes	Yes	No
EU26	Portugal	Yes	Yes	Yes	No
EU26	Romania	Yes	Yes	No	No
EU26	Slovakia	Yes	Yes	Yes	No
EU26	Slovenia	Yes	Yes	Yes	No
EU26	Spain	Yes	Yes	Yes	No
EU26	Sweden	Yes	Yes	Yes	No
Eastern Africa	Mozambique	No	Yes	No	No
Ireland	Ireland	Yes	Yes	Yes	No
Middle Africa	Angola	No	Yes	No	Yes
Middle Africa	Equatorial Guinea	No	No	No	Yes
Middle East	Iran	No	No	No	Yes
Middle East	Iraq	No	No	No	Yes
Middle East	Israel	No	Yes	Yes	No
Middle East	Jordan	No	Yes	No	No
Middle East	Kuwait	No	Yes	No	Yes
Middle East	Oman	No	Yes	No	No
Middle East	Qatar	No	Yes	No	Yes
Middle East	UAE	No	Yes	No	Yes
Middle East	Yemen	No	Yes	No	No
North America	Canada	No	Yes	Yes	No
North America	Mexico	No	Yes	Yes	No
North America	US	No	Yes	Yes	No
Northern Africa	Algeria	No	No	No	Yes
Northern Africa	Egypt	No	Yes	No	No
Northern Africa	Libya	No	No	No	Yes
Northern Africa	Morocco	No	Yes	No	No
Northern Africa	Tunisia	No	Yes	No	No
Other Europe	Georgia	No	Yes	No	No
Other Europe	Macedonia	No	Yes	No	No
Other Europe	Norway	No	Yes	Yes	No
Other Europe	Serbia	No	No	No	No
Other Europe	Switzerland	No	Yes	Yes	No
Other Europe	Turkey	No	Yes	Yes	No
South America	Argentina	No	Yes	No	No
South America	Bolivia	No	Yes	No	No

Sub-Region	Country	Associations			
		EU	WTO	OECD	OPEC
South America	Brazil	No	Yes	No	No
South America	Chile	No	Yes	Yes	No
South America	Colombia	No	Yes	No	No
South America	Peru	No	Yes	No	No
South America	Uruguay	No	Yes	No	No
South America	Venezuela	No	Yes	No	Yes
Southern Africa	South Africa	No	Yes	No	No
UK	UK	Yes	Yes	Yes	No
Western Africa	Ghana	No	Yes	No	No
Western Africa	Nigeria	No	Yes	No	Yes

*CIS is Commonwealth of Independent States