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The price and income elasticities of natural gas demand: International evidence

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Natural gas contributes a growing share of the world's energy mix. In this paper we use national-level data for a sample of 44 countries to estimate the price and income elasticities of natural gas demand. We present both single-equation results and results instrumenting natural gas prices with proved natural gas reserves. Our instrument includes both domestic reserves and distance-weighted reserves in other countries. We obtain estimates of the average long-run price elasticity of natural gas demand of around –1.25 and of the average long-run income elasticity of natural gas demand of +1 and higher. We also present separate estimates for final natural gas demand by industry and households.

Keywords: natural gas, price, income, elasticity, demand

JEL classifications: Q41, Q31, Q43

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1. Introduction

Natural gas contributed 21% of the global energy mix in 2013, up from 16% in 1971 (International Energy Agency [IEA], 2015a). There is sizeable variation in the importance of natural gas in national energy mixes, with both high-income countries and countries rich in natural gas deposits tending to be more reliant on this energy source (Burke, 2013). Relatively strong growth in natural gas use is expected over coming decades, with the IEA (2011) referring to a "golden age" for natural gas and expecting the fuel's share of the global energy mix to increase to 23–24% by 2040 in its "new policies" and "current policies" scenarios (IEA, 2015b). Recent booms in shale gas and coal seam gas are helping to fuel this expansion.

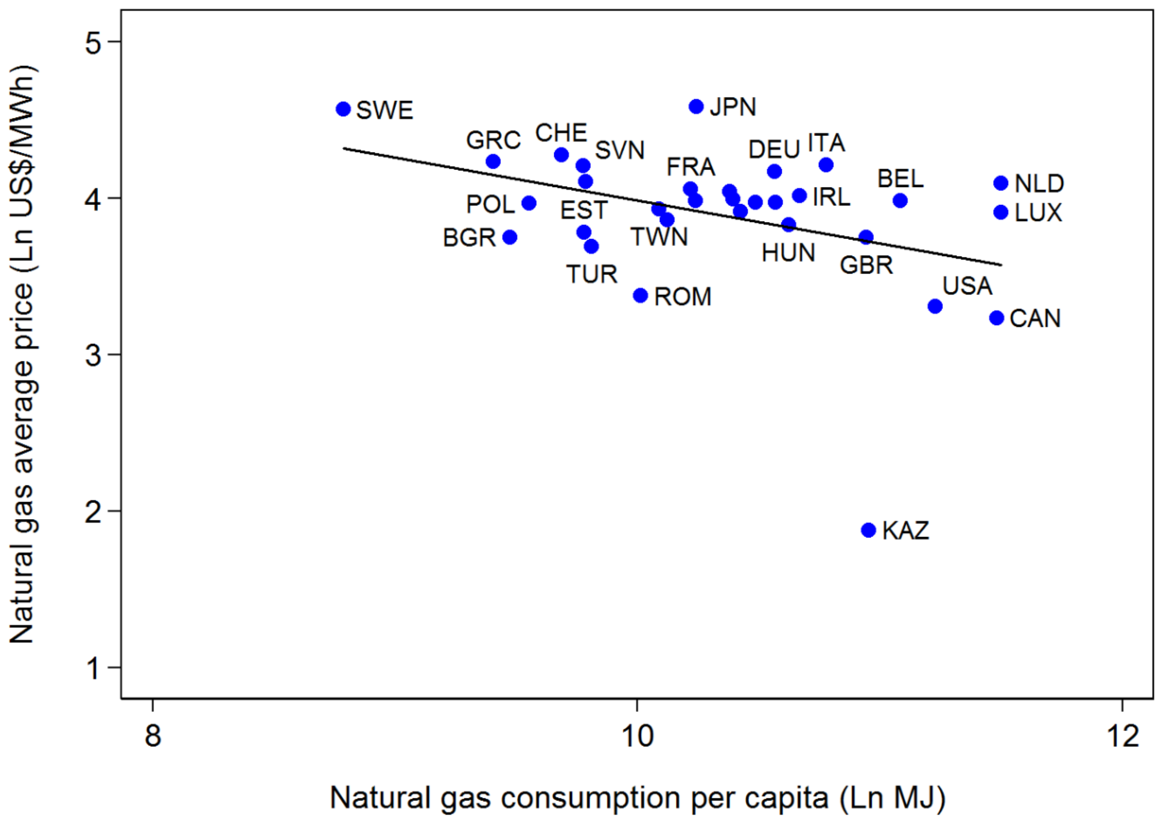
There are large differences in end-user natural gas prices between countries (Holz et al., 2015; Makholm, 2015). These result from the costs involved in transporting natural gas by pipeline or in liquefied form, local tax/subsidy policies, and other factors. The IEA (2015b) estimates that price subsidies for consumers of natural gas equaled $107 billion globally in 2014, more than half of which was in only four countries (Iran, Russia, the United Arab Emirates, and Saudi Arabia). Consumer subsidies for natural gas are a product of policies such as price regulations and domestic natural gas reservations.

Natural gas is composed mostly of methane (CH_4), but can also have proportions of ethane, propane, butane, pentane, carbon dioxide, nitrogen, hydrogen sulfide, and/or water. Humans use the fuel for heating, transport, industrial operations, electricity generation, and other purposes. Natural gas-fired electricity generation plants offer flexibility to the electricity generation system through relatively fast start-up and ramping speeds (Neumann and von Hirschhausen, 2015). Relative to coal and oil, natural gas is also associated with fewer emissions of carbon dioxide (CO_2) or local pollutants such as nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulates (IEA, 2011). Methane leakage during the extraction, processing, and transport of natural gas reduces its greenhouse benefits, however (Howarth, 2014). Transport costs mean that international trade in natural gas occurs within several regional markets, each with different prices (IEA, 2015b).

In this study we use national-level data for 44 countries over the period 1978–2011 to obtain aggregate estimates of the price and income elasticities of natural gas demand. We also estimate separate elasticities for total natural gas consumption by industry and households. Understanding the sizes of these elasticities is useful for parameterizing energy-economy models. Knowing the price elasticity of natural gas demand is also useful for understanding the effects of adjustments to tax settings for natural gas, as well as the local consumption effects of opening natural gas markets to international trade. Countries maintaining artificially low domestic natural gas prices – a group that even includes net importers such as China (Razavi, 2009; IEA, 2011; Aolin and Qing, 2015; Lin et al., 2015; Paltsev and Zhang, 2015) – could use our estimates to forecast the implications of natural gas price reform for domestic natural gas consumption.

Figure 1 plots the average of end-user natural gas prices for (a) industry and (b) households against natural gas consumption per capita for 31 countries in 2010, both logged. The fitted line has the appearance of a downward-sloping demand curve: lower natural gas prices are on average associated with higher per capita natural gas consumption. The Figure also illustrates substantial cross-country variation in both natural gas prices and per capita natural gas consumption. In our regressions we will include additional variables that help to explain natural gas consumption.

Figure 1. Natural gas prices and per capita consumption, 2010



Notes: Covers 31 countries. The average price is the simple mean of the average prices paid by (a) industry and (b) households. Consumption covers all primary energy derived from natural gas. The year 2010 is used as more observations are available for this year than for 2011. World Bank country codes are used. Price is shown on the *y*-axis in line with the standard presentation of a demand curve. Sources: IEA (2015a, 2015c).

This paper builds on a body of research estimating the price and income elasticities of demand for natural gas, often for a specific sector in a single country. There are advantages to our aggregate approach. First is that our study is able to span countries representing 50% of the world's population and 72% of global natural gas consumption as of 2011. Aggregate elasticities are also useful for modelling macro-level trends in natural gas use. It should be expected that the price elasticity of demand for natural gas is more elastic at the aggregate level than in some micro-level contexts, as there are more substitution possibilities at higher levels of aggregation.

A key contribution of our paper is the use of a supply-side instrumental variable (IV) strategy to address the potential for endogeneity in natural gas prices. We instrument each country's natural gas price with the proved (and yet to be extracted) natural gas reserves of that country and of other countries, where other countries' natural gas reserves are weighted using a negative power function of distance. The instrument gives a higher weight to reserves in nearby countries and a lower weight to reserves in distant countries. Our instrument is measured in million cubic feet per capita. Natural gas reserves is a potentially suitable instrument because countries that are rich in natural gas, or that have neighbors rich in natural gas, tend to have lower natural gas prices on account of the smaller transport and other transactions costs from extraction point to market. Countries with natural gas endowments and/or access to nearby supplies are also more likely to supply below-cost or lowly-taxed natural gas to domestic consumers. An example is Kazakhstan (Figure 1). Our IV exclusion restriction is that natural gas reserves affect natural gas demand only via the natural gas price.

The paper proceeds as follows. Section 2 discusses our method and data. Section 3 presents our results. Section 4 compares the results to prior estimates. The final section concludes.

2. Method and data

2.1 Specification

We begin by estimating a cross-country aggregate demand function for natural gas consumption (G) in country c during 2010:

$$\ln G_c = \alpha + \beta \ln P_c + \gamma \ln Y_c + \delta \ln S_c + \eta \ln L_c + \theta T_c + \kappa \ln D_c + \varepsilon_c \qquad (1)$$

where P is the average end-user price of natural gas, calculated as the simple mean of the end-user prices for industry and households. Y is gross domestic product (GDP) per capita, S is the size of each country's population, L is land area, T is average temperature in ˚C,[1] D is the price of road-sector gasoline (a proxy for the price of oil substitutes), and ε is an error term. Eq. (1) uses between variation, which means that coefficients will have a long-run interpretation on the assumption that variables are settled at long-run equilibria (Pesaran and Smith, 1995). We expect β (the long-run price elasticity of demand) to be negative and γ (the long-run income elasticity of demand) to be positive. δ is expected to be positive, as larger populations are likely to consume more natural gas. We expect θ to be negative, as natural gas is commonly used for heating purposes in cold climates. 2010 is used for our cross-section estimates as it allows for a larger

[1] The average temperature is not logged as it is zero or negative in some or all years in Canada, Finland, and Russia.

sample of countries than is available for 2011. Our use of natural gas consumption (cf. production) data and the end-user (cf. extraction) price is as is suitable for estimating a demand (cf. supply) function.

We have access to data for more than one year (*y*), allowing us to form a country-level panel, albeit one that is unbalanced due to missing observations. We thus proceed to a panel specification:

$$\ln G_{c,y} = \alpha + \beta \ln P_{c,y} + \gamma \ln Y_{c,y} + \delta \ln S_{c,y} + \eta \ln L_{c,y} + \theta T_{c,y} + I_y + I_c + \varepsilon_{c,y} \qquad (2)$$

where *D* has been removed due to data limitations.

We use three panel estimators:

a) *Between estimator*, which uses the mean of each series for each country, and so exploits only between variation; the between estimates exclude the year dummies (I_y) and country dummies (I_c)
b) *Pooled ordinary least squares (OLS)* with year dummies but no country dummies
c) *Fixed-effects estimator* with year dummies, i.e. the full Eq. (2)

The between estimator is thought to provide long-run estimates, and, like the cross-sectional estimator, avoids time series issues such as the existence of unit roots and the precise specification of dynamics (Baltagi and Griffin, 1983, 1984; Pirotte, 1999, 2003; Baltagi, 2008; Stern, 2010). The static fixed-effects estimator controls for time-invariant country characteristics such as geography but, by focusing on within variation, is likely to pick up shorter-run effects. Shorter-run effects should be expected to be smaller than long-run effects, as it likely takes time for natural gas use to respond to price changes, especially given the importance of long-run contracts (Neumann and von Hirschhausen, 2015) and of infrastructure lock-in in energy markets. Estimates from static pooled OLS regressions might be expected to lie somewhere in-between the between estimates and the static fixed-effects estimates. An alternative approach to obtain long-run elasticities is to estimate a distributed lag model. We find that the long-run price elasticity from fixed-effects distributed lag models converges to the price elasticity obtained using the between estimator. The relatively short and unbalanced time-series component of the data does not suit a country-by-country time-series analysis.

While data constraints prevent us from directly controlling for the prices of all energy substitutes, changes in prices of globally-traded energy sources (e.g. oil) are captured by the year fixed effects in our pooled OLS and fixed-effects estimates. As will be mentioned, we also obtain similar results controlling for each country's per capita oil and coal reserves, measures that are likely to be correlated with final consumer prices of oil and coal (Burke and Nishitateno, 2013). It would be undesirable to control for electricity prices, as natural gas is an input to electricity generation as well as an end-use substitute for electricity.[2]

In additional specifications we estimate the price and income elasticities of final use of natural gas by industry and households using the average end-user prices paid by these sectors.[3] Globally, industry and households accounted for 36% and 30% of final use of natural gas in 2011, respectively (IEA, 2015a).[4] We maintain the same control set for these industry and household final-use regressions. With the exception of the between estimates, we present standard errors that are robust to heteroskedasticity, and – for the panel estimates – clustered by country to allow for country-by-country patterns of autocorrelation.

2.2 Instrumental variable strategy

Estimating demand functions is subject to a famous endogeneity challenge: price and quantity may be jointly determined, so it is not certain that a single-equation framework will provide consistent estimates.[5] Specifically, each country's natural gas demand should be expected to have an influence on each country's natural gas price if the natural gas supply curve is not perfectly elastic. Estimates of the long-run price elasticity of natural gas supply are positive and finite (Krichene, 2002), meaning that potential endogeneity is indeed important to consider.

To address endogeneity concerns we present estimates using per capita proved natural gas reserves as an instrument for the natural gas price. This is similar to Burke and Nishitateno (2013)'s use of per capita oil reserves to instrument for the gasoline price when estimating the demand function for gasoline.[6] Because natural gas reserves in neighboring countries are likely to influence each country's natural gas price, we define our instrument to include not only domestic natural gas reserves, but also distance-weighted reserves in other countries, using a negative power weighting approach. The instrument is:

$$\left(R_{c,y} + \sum_{i=1}^{69} d_{ic}{}^{-1} R_{i,y}\right)/S_{c,y} \qquad (3)$$

where *R* is proved natural gas reserves in million cubic feet, *i* indexes other countries, and *d* is the simple distance between the most populous cities in country *c* and country *i*, in kilometers. The 69 other countries include every country with year-2011 proved natural gas reserves equal to

[2] Natural gas accounted for 22% of global electricity generation in 2013 (IEA, 2015a).
[3] Final natural gas use covers only direct consumption by end-use sectors, and does not include energy generated using natural gas but delivered in another form such as electricity. At the national level, primary use covers all uses.
[4] Equivalent to 15% and 17% of global primary natural gas use, respectively.
[5] The identification of demand and supply was the spur to the development of the instrumental variable approach. See Angrist and Krueger (2001) for a review.
[6] Burke and Nishitateno (2015) also use the approach in exploring how gasoline prices influence road fatalities.

or exceeding 1 trillion cubic feet (including countries not in our estimation sample). Our approach means that the natural gas reserves of a country 50 kilometers away are weighted at 0.04% of their actual value; 100 kilometers away at 0.01%; and 1,000 kilometers away at 0.0001%. The instrument hence primarily considers each country's domestic reserves and the reserves of near neighbors. Our approach of allocating low weights to reserves in distant countries is suitable given the relatively high transport costs of natural gas. Our paper is the first to use natural gas reserves to instrument natural gas prices.

The first requirement for our instrument to be valid is that per capita natural gas reserves are indeed correlated with natural gas prices. Given the high transport costs for natural gas and the likelihood of higher natural gas taxes in natural gas-poor countries and price subsidies in natural gas-rich countries, we hypothesize that there is a negative correlation between per capita natural gas reserves and natural gas prices. Tests will confirm this negative correlation and also that our instrument is typically able to provide strong first-stage identification.

The second requirement is that per capita natural gas reserves are independent of ε, so that natural gas reserves affect the quantity of natural gas demanded only via the natural gas price. If natural gas-rich countries (or countries with natural gas-rich neighbors) are more likely to use natural gas at any given price, this requirement would not be satisfied. It is possible that this is the case: governments of natural gas-rich countries may use non-price mechanisms to encourage natural gas use in an effort to achieve domestic energy self-sufficiency, for example. While our IV approach is thus not without limitation, we believe it worth pursuing given that the dominant channel via which domestic endowments of natural gas are likely to affect natural gas consumption is via a lower required price to purchase natural gas. Our approach also involves assuming that historical exploration effort for natural gas is not a function of current domestic demand for this fuel. This is in part able to be justified by the fact that the domestic market is only one source of demand for any country's natural gas, so incentives for exploration exist even in the context of low domestic demand.[7] Current extraction of natural gas affects reserves and may contaminate our instrument, but we obtain similar results instrumenting with five-year lagged per capita natural gas reserves.[8]

A final note on our instrument is that it primarily provides information useful for identifying *cross-country* differences in natural gas prices. The time-series dimension of the instrument is likely to be less useful, as (a) year-to-year variation in proved natural gas reserves is not always reflective of on-the-ground changes[9]; and (b) final end-user prices are likely to often take time to

[7] Exploration effort may be a function of variables such as GDP per capita, but GDP per capita is controlled for in our regressions.
[8] We also obtain a similar single-equation estimate using a five-year lagged natural gas price term.
[9] Russia's proved natural gas reserves have only been updated once during 1997–2011, for example. For some countries, there are some sudden revisions in natural gas reserves.

adjust to changes in natural gas supply, for reasons including that some prices are regulated and that long-term contracts have historically been an important feature of the natural gas market. For this reason, and to minimize challenges associated with weak instruments, we do not use our instrument in our fixed effects estimates.

2.3 Data

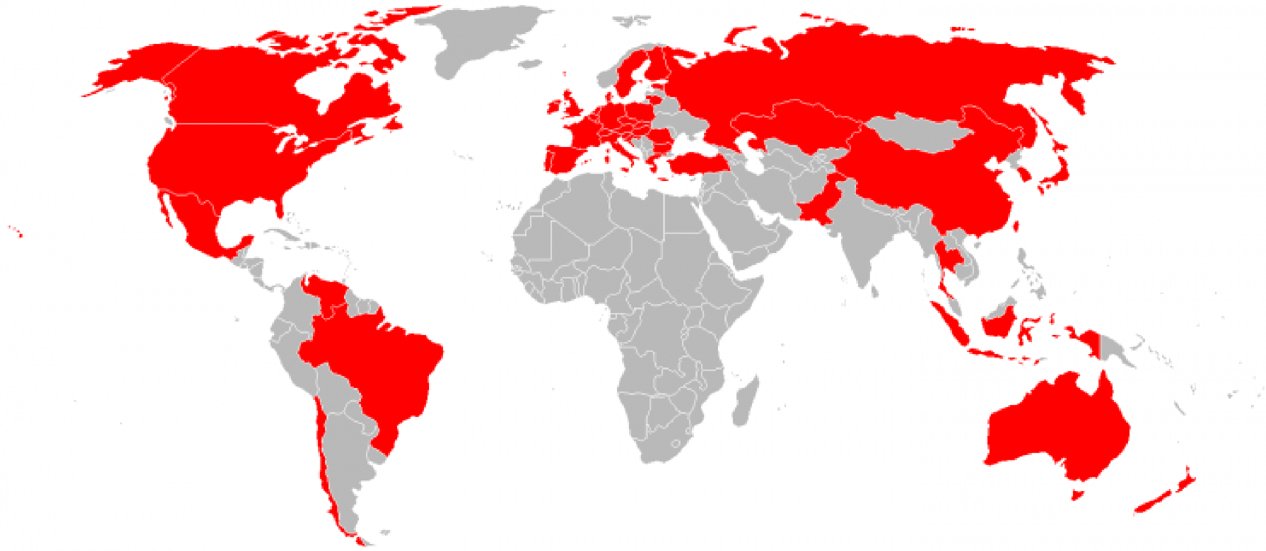
We use national-level data on natural gas consumption and prices from the IEA (2015a, 2015c). The IEA's price data are the best we are aware of for an aggregate study with broad country and time coverage. *P* is measured in US$ per megawatt hour (MWh), deflated using the GDP deflator of the United States.[10] For our panel sample, total natural gas use by industry is similar in magnitude to total natural gas use by households, meaning that the simple average of prices for the two groups is similar to the weighted average. The prices include fixed charges; the data do not allow us to separate out the effect of marginal charges. *Y*, obtained from Feenstra et al. (2015), is in purchasing power parity terms and, like *P*, is measured in real US$. *T* is each country's average annual temperature as reported by Harris et al. (2014). We obtain data on *S*, *L*, and *D* from the World Bank (2015). Natural gas reserves are as reported by the U.S. Energy Information Administration (2015). Distance data are from CEPII (2016). A complete list of variable definitions and sources is provided in the Appendix.

Our reported estimations cover 44 countries over the 34-year period 1978–2011. Non-availability of natural gas price data for some country-years reduces individual sample sizes, however, with our panel for aggregate natural gas demand covering 775 country-year observations from 39 countries. Larger samples can be used in the regressions for industry and households. The IEA (2015c) also provides data on the natural gas prices faced by the electricity generation sector, but we do not use this series as it covers a smaller number of country-years.

Of the 34 current members of the Organisation for Economic Co-operation and Development (OECD), only Iceland, Israel, and Norway do not appear in our sample due to missing price data and, in the case of Iceland, zero reported use of natural gas. Our dataset also includes Russia, China, Indonesia, Thailand, Pakistan, Venezuela, Kazakhstan, Brazil, Chinese Taipei, Romania, Lithuania, Bulgaria, and Croatia (ordered from largest to smallest primary consumer of natural gas in 2011). 2011 is the final year for which the IEA (2015c) natural gas price data are available for non-OECD countries, which is the reason our sample ends in this year. The countries in our sample are shown in Figure 2.

[10] Similar results are obtained if we (a) do not deflate, or (b) deflate with the US consumer price index.

Figure 2. Countries in our sample



Note: 44 countries in total. See Table 1 for a list.

Before proceeding to the results, Table 1 presents data for our instrument. The table is for the year 2011 for the 44 countries in our estimation sample, and in aggregate rather than per capita terms. The countries with the largest natural gas reserves in our study are Russia, the United States, Venezuela, and Australia. Our measure including distance-weighted reserves is on average 3% larger than the domestic reserves measure. The most notable effect of adding in distance-weighted reserves is for some European countries that are themselves natural gas-poor, but have natural gas-rich neighbors. Lithuania, for example, has 3.54 trillion cubic feet of natural gas reserves assigned to it by our instrument, primarily due to its proximity to Russia.

3. Results

3.1 Aggregate estimates

Results for aggregate primary use of natural gas are presented in Table 2, with the single-equation estimates shown in columns 1–4 and the IV estimates in columns 5–7.

Focusing firstly on the single-equation estimates, the price elasticities of demand in the cross-sectional and between estimates are both near –1.25. The similarity of these estimates suggests that the long-run price elasticity of natural gas demand has been quite stable over time. This elasticity is significantly different from 0 at the 1% level. We are unable to reject the null hypotheses that the elasticity equals –1. The point estimate of the price elasticity of demand in the fixed-effects specification is –0.55, consistent with this estimator picking up shorter-run effects. The pooled OLS estimate is –0.95. The point estimates of the income elasticities of natural gas demand are +1.01 to +1.65 in the first three columns, with tests unable to reject the nulls that natural gas demand has unit income elasticity. The income elasticity in the fixed-effects specification is 0.70. The long-run population elasticities are quite close to unity. The results provide no significant evidence that land area, average temperature, or the gasoline price have any effects on natural gas use.[11]

Table 1. Measures of natural gas reserves

Country	Proved reserves	Proved reserves + distance-weighted proved reserves in other countries	Country	Proved reserves	Proved reserves + distance-weighted proved reserves in other countries
Russia	1,680.00	1,681.48	Croatia	0.88	3.19
United States	304.63	305.47	Finland	0.00	3.17
Venezuela, RB	178.86	179.56	Austria	0.57	2.98
Australia	110.00	110.51	Turkey	0.22	2.96
China	107.00	108.06	Slovak Republic	0.50	2.94
Indonesia	106.00	106.87	Hungary	0.29	2.80
Kazakhstan	85.00	87.11	Bulgaria	0.20	2.72
Canada	61.95	63.23	Sweden	0.00	2.70
Netherlands	49.00	50.99	Czech Republic	0.14	2.52
Pakistan	29.67	32.03	Greece	0.04	2.43
Brazil	12.94	13.58	Slovenia	0.00	2.26
Mexico	11.97	12.63	Belgium	0.00	2.23
Thailand	11.03	12.20	France	0.24	2.20
United Kingdom	9.04	10.94	Luxembourg	0.00	2.14
Poland	5.82	8.68	Switzerland	0.00	2.06
Germany	6.20	8.49	Ireland	0.35	2.04
Romania	2.23	4.97	Spain	0.09	1.77
Denmark	2.05	4.48	New Zealand	1.21	1.71
Italy	2.25	4.36	Japan	0.74	1.61
Chile	3.46	4.01	Portugal	0.00	1.47
Lithuania	0.00	3.54	Chinese Taipei	0.22	1.20
Estonia	0.00	3.23	Korea, Rep.	0.04	1.08

Notes: The unit is trillion cubic feet. The distance-weighted measure is defined in the text. Countries are listed in descending order of the distance-weighted measure. A per capita version, in million cubic feet, is used as the instrument. The table shows the 44 countries in our estimation sample.

The IV estimations in Table 2 achieve relatively strong first-stage identification, with *F* statistics on the instrument exceeding 20.[12] These regressions pass the Stock and Yogo (2005) test for weak instruments. The instrument has the expected negative sign in the first stage, with an additional million cubic feet of proved natural gas reserves per capita on average associated with natural gas prices being around 20% lower, holding the other variables constant. For context, the panel sample-average natural gas reserves (including distant-weighted reserves overseas) is 0.94 million cubic feet per capita, with a minimum of 0.01 (Japan) and maximum of 11.67 (Russia).

[11] We continue to find an insignificant temperature effect if we use the average temperature of the coldest month of each year in place of the average temperature of the year.
[12] The first-stage *F* statistic for the instrument is not available for the IV between estimator.

Table 2. Results for aggregate natural gas use

Dependent variable: Ln Natural gas consumption (primary)$_{c,y}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Single equation				IV		
Specification	Cross-section (2010)	BE	Pooled	FE	Cross-section (2010)	BE	Pooled
Ln Natural gas price (average of industry and household prices; real)$_{c,y}$	-1.25***	-1.26***	-0.95***	-0.55***	-1.37***	-1.15**	-1.58***
	(0.37) [0.50]	(0.35) [0.46]	(0.21) [0.83]	(0.16) [0.01]	(0.47) [0.43]	(0.52) [0.76]	(0.52) [0.27]
Ln GDP per capita$_{c,y}$	1.01***	1.65***	1.39***	0.70**	1.05***	1.53**	1.92***
	(0.20) [0.96]	(0.56) [0.25]	(0.28) [0.17]	(0.32) [0.35]	(0.20) [0.81]	(0.70) [0.45]	(0.49) [0.06]
Ln Population$_{c,y}$	1.20***	1.06***	1.06***	0.41	1.21***	1.05***	1.15***
	(0.13)	(0.18)	(0.10)	(1.30)	(0.12)	(0.19)	(0.15)
Ln Land$_{c,y}$	-0.19	-0.08	-0.02		-0.20	-0.06	-0.14
	(0.14)	(0.15)	(0.10)		(0.12)	(0.17)	(0.14)
Temperature (°C)$_{c,y}$	-0.02	0.01	-0.02	-0.01	-0.02	0.01	-0.01
	(0.03)	(0.03)	(0.02)	(0.05)	(0.03)	(0.03)	(0.02)
Ln Gasoline price$_{c,y}$	0.53				0.66		
	(0.42)				(0.54)		
Year fixed effects	No	No	Yes	Yes	No	Yes	No
Observations	31	775	775	775	31	775	775
Countries	31	39	39	39	31	39	39
R^2	0.93	0.74	0.79	0.55	0.93	0.74	0.76
First stage:							
Coefficient for instrument	-	-	-	-	-0.20***	-0.19***	-0.16***
Instrument F statistic	-	-	-	-	24.70	n.a.	38.81

Notes: ***, **, and * indicate statistical significance at 1, 5, and 10%. With the exception of the between estimates, standard errors (in parentheses) are robust and, for pooled and FE estimates, clustered at the country level. The figures in square brackets are *p*-values from tests that the price elasticity equals –1 or income elasticity equals +1. The R^2s reflect the power of the explanatory variables, except country fixed effects. Coefficients on constants and country and year fixed effects are not reported. Ln Land is excluded from the FE estimation given its lack of time-series variation. The instrumented variable is the log natural gas price. This is instrumented by natural gas reserves per capita (including distance-weighted reserves of other countries; see Eq. (3)). The Stock-Yogo 5% critical value for 10% (15%) maximal IV size is 16.38 (8.96). The null of a weak instrument is rejected if the F statistic on the instrument exceeds the Stock-Yogo critical value. BE = between estimator. FE = fixed effects. IV = instrumental variable. n.a = not available.

The second-stage IV results are quite similar to the single-equation results, suggesting that price-quantity endogeneity issues might not in the end be substantial when estimating the demand function for natural gas use at the aggregate level.[13] The cross-sectional and between IV estimates of the long-run price elasticity of natural gas demand are –1.37 and –1.15, with *t*-tests unable to reject the (separate) nulls that each equals –1. The most notable difference relative to the single-equation results is the larger price and income elasticity estimates for the pooled specification. The results on the controls are similar. The R^2 values in Table 2 are high, suggesting that 74–93% of the between variation and around 55% of the within variation in log natural gas consumption is explained by the variables in our model.

3.2 Estimates for industry and households

Table 3 presents results for final consumption of natural gas by industry, still aggregated nationally. The price variable is the log real average natural gas price paid by the industrial sector. Income continues to be measured by log national GDP per capita. Focusing firstly on the single-equation specifications, the estimated price elasticity of demand in the cross-sectional estimate in column 1 is –1.21, similar to the result for aggregate natural gas use in Table 2. The between estimate is smaller (–0.82). It is not possible to reject the nulls that each of these elasticities equal –1. The fixed-effects price elasticity is smaller still (–0.37), likely a shorter-run response. The income elasticities of demand continue to be statistically indistinguishable from +1, except in the fixed-effects estimate.

The IV estimates in Table 3 continue to suggest that the long-run price elasticity of natural gas demand by industry is around –1. One exception is the cross-sectional IV estimate in column 5, although the first-stage identification in this column is relatively weak (*F* statistic on the instrument = 6). We obtain a slightly larger point estimate of this price elasticity (–0.72) using the Fuller (1977) estimator, which allows for improved inference when instruments are weak. Stronger first-stage identification is obtained in the panel estimates in columns 6–7. The pooled IV estimate is remarkably similar to the pooled single-equation estimate. Once again we conclude that addressing endogeneity does not substantially alter our conclusions on the price elasticity of natural gas use.

Table 4 presents estimates for final consumption of natural gas by households. The long-run price elasticity point estimates remain similar, but the fixed-effect estimate becomes very small (–0.13) and is not significantly different from zero. This suggests that household natural gas demand is very inelastic in the short run. The income elasticity point estimates are greater than +1 in all except the fixed effects estimate, reflecting strong growth in household natural gas use as incomes rise.

[13] A similar conclusion was reached by Burke and Nishitateno (2013) for road-sector gasoline.

Table 3. Results for industry

Dependent variable: Ln Natural gas consumption by industry (final)$_{c,y}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Single equation				IV		
Specification	Cross-section (2010)	BE	Pooled	FE	Cross-section (2010)	BE	Pooled
Ln Natural gas price (industry; real)$_{c,y}$	-1.21**	-0.82***	-1.00***	-0.37***	-0.62	-1.09**	-1.00**
	(0.48) [0.67]	(0.26) [0.50]	(0.16) [0.99]	(0.13) [0.00]	(0.63) [0.55]	(0.50) [0.86]	(0.41) [0.99]
Ln GDP per capita$_{c,y}$	0.71***	1.29***	1.17***	0.40	0.65***	1.47***	1.17***
	(0.23) [0.21]	(0.32) [0.36]	(0.22) [0.44]	(0.29) [0.04]	(0.22) [0.11]	(0.43) [0.27]	(0.28) [0.54]
Ln Population$_{c,y}$	1.25***	0.81***	0.93***	1.48	1.17***	0.83***	0.93***
	(0.15)	(0.13)	(0.09)	(1.03)	(0.15)	(0.14)	(0.12)
Ln Land$_{c,y}$	-0.34*	-0.05	-0.02		-0.22	-0.10	-0.02
	(0.18)	(0.12)	(0.08)		(0.20)	(0.15)	(0.12)
Temperature (°C)$_{c,y}$	-0.05***	-0.00	-0.03*	0.00	-0.05***	-0.00	-0.03*
	(0.02)	(0.02)	(0.02)	(0.04)	(0.02)	(0.02)	(0.02)
Ln Gasoline price$_{c,y}$	0.46				0.05		
	(0.49)				(0.60)		
Year fixed effects	No	No	Yes	Yes	No	No	Yes
Observations	34	840	840	840	34	840	840
Countries	34	43	43	43	34	43	43
R^2	0.90	0.72	0.79	0.27	0.89	0.72	0.79
First stage:							
Coefficient for instrument	-	-	-	-	-0.07**	-0.14***	-0.16***
Instrument *F* statistic	-	-	-	-	5.98	n.a.	17.98

Notes: Same as for Table 2.

Table 4. Results for households

Dependent variable: Ln Natural gas consumption by households (final)$_{c,y}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Single equation				IV		
Specification	Cross-section (2010)	BE	Pooled	FE	Cross-section (2010)	BE	Pooled
Ln Natural gas price	-1.43***	-0.90**	-0.64***	-0.13	-1.36***	-1.13**	-1.44**
(household; real)$_{c,y}$	(0.43) [0.32]	(0.34) [0.76]	(0.17) [0.04]	(0.16) [0.00]	(0.46) [0.44]	(0.49) [0.80]	(0.65) [0.50]
Ln GDP per capita$_{c,y}$	1.35***	2.62***	2.10***	0.58	1.32***	2.94***	2.94***
	(0.34) [0.32]	(0.68) [0.02]	(0.41) [0.01]	(0.57) [0.47]	(0.33) [0.34]	(0.84) [0.02]	(0.80) [0.02]
Ln Population$_{c,y}$	1.69***	1.35***	1.36***	-0.62	1.69***	1.36***	1.49***
	(0.14)	(0.23)	(0.21)	(2.84)	(0.13)	(0.23)	(0.25)
Ln Land$_{c,y}$	-0.49***	-0.32*	-0.27		-0.49***	-0.36*	-0.37*
	(0.16)	(0.18)	(0.16)		(0.15)	(0.19)	(0.19)
Temperature (°C)$_{c,y}$	-0.12***	-0.07	-0.08*	0.01	-0.12***	-0.06	-0.06
	(0.03)	(0.04)	(0.04)	(0.11)	(0.03)	(0.04)	(0.04)
Ln Gasoline price$_{c,y}$	1.43**				1.34**		
	(0.61)				(0.67)		
Year fixed effects	No	No	Yes	Yes	No	No	Yes
Observations	35	850	850	850	35	850	850
Countries	35	40	40	40	35	40	40
R^2	0.87	0.65	0.61	0.28	0.87	0.65	0.56
First stage:							
Coefficient for instrument	-	-	-	-	-0.25***	-0.24***	-0.19***
Instrument *F* statistic	-	-	-	-	10.24	n.a.	19.99

Notes: Same as for Table 2.

In Tables 3 and 4 we find some evidence that industry and households in countries with warmer temperatures use less natural gas, and that countries with larger land masses also use less natural gas (*ceteris paribus*). The latter may be because natural gas distribution networks are less viable in less densely populated countries. We also find evidence that natural gas and gasoline appear to be substitutes for households: where the price of gasoline is higher, households tend to consume more natural gas. The variables in our model explain the majority of the cross-country variation in household natural gas use, but less than one-third of the year-to-year within variation.

3.3 Distributed lag models

Table 5 presents distributed lag specifications, for which we revert back to aggregate primary natural gas use. The distributed lags allow us to examine the dynamics of natural gas responses to price changes and obtain an alternative estimate of the long-run price elasticity of demand. We employ country fixed effects, year dummies, and single-equation estimations. Lagged price terms back to *y*–8 are included. Lagged income terms were also tested, but were statistically insignificant and so we excluded them.

The estimate in column 9 of Table 5 provides a long-run price elasticity of natural gas demand of –0.68, only slightly larger than the elasticity from the static fixed-effects estimate (–0.55). The –0.68 point estimate is not statistically different from –1, and is similar to the between estimate for the same sub-sample (see the base of Table 5). The estimates suggest that the long-run effect from a distributed lag model converges to the between estimate as additional lags are added, as expected if both estimators are providing long-run effects.[14] Unfortunately, adding lagged price terms reduces the sample size. Because the between estimator provides a larger price elasticity for the full sample (–1.26), it seems appropriate to conclude that our best estimate of the long-run price elasticity of natural gas demand is unity or above. Table 5's estimates of the aggregate income elasticity of demand are generally close to unity.

3.4 Robustness issues

We here discuss the effects of some additional estimation issues. Our results are similar in single-equation and IV estimates that also control for each country's per capita oil and coal reserves, which reduces the concern that results are confounded by oil and coal availability and prices. We also obtain quite similar long-run price and income elasticities of natural gas demand when including region dummies (using the World Bank classifications). Using an interaction between the log natural gas price and log GDP per capita, we find no significant evidence that the price elasticity of natural gas demand differs for countries at different per capita income levels.

One potentially confounding factor is environmental effort: countries with strict environmental stances may have both higher fossil fuel taxes and additional policies to reduce fossil fuel use,

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[14] The same was reported by Burke and Nishitateno (2015). See also Pirotte (1999).

such as energy efficiency standards. To consider this, we included a control measuring the log per capita CO_2 emissions from the use of fossil fuels and the manufacture of cement (from the World Bank, 2015) as a catch-all proxy for environmental effort. Our estimates for the price and income elasticities of natural gas remain similar.

We also investigated alternative definitions of our instrument. We obtain quite similar second-stage point estimates, but weaker first-stage identification, instrumenting with only domestic proved natural gas reserves per capita (i.e. $R_{c,y}/S_{c,y}$). The same is true using an instrument that uses a distance weighting power of –0.5 instead of –1, which places a larger weight on other countries' reserves. Our robustness checks are laid out in our estimation commands, available online.

Publication bias has recently been found to be a concern in estimates of price and income elasticities of energy demand (Havranek et al., 2012; Havranek and Kokes, 2015), as well as other fields of research in energy economics (e.g. Havranek et al., 2015) and economics more broadly (e.g. Havránek, 2015). In response to this issue, we would like to reflect on our approach. We have used the maximum sample size for each estimation, with the principal constraint to a larger sample being the availability of data on natural gas prices. We did not have a strong prior on what the precise price or income elasticities of natural gas demand are, although economic intuition suggested that they are likely to be negative and positive, respectively. Our focus was on implementing a technique able to provide a reliable estimate. In doing so we built off the estimation strategies employed in the first author's prior research (e.g. Burke and Nishitateno, 2013, 2015; Burke 2014; Burke and Liao, 2015), but with application to natural gas. We note that not all of our results are statistically significant: column 5 of Table 3 and column 4 of Table 4 provide insignificant estimates of the price elasticity of natural gas demand, for example. We also obtain some insignificant coefficients for income (in two fixed-effects estimates) and the control variables (frequently). We have no conflict of interest to declare. Our approach – including the online provision of our data and estimation commands – involves a high standard of transparency.

Table 5. Distributed lag results

Dependent variable: Ln Natural gas consumption (primary)$_{c,y}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ln Natural gas price (average of industry and household prices; real)$_{c,y}$	-0.55***	-0.25**	-0.28***	-0.22**	-0.22**	-0.25***	-0.22***	-0.23***	-0.23***
	(0.16)	(0.10)	(0.08)	(0.09)	(0.09)	(0.09)	(0.07)	(0.08)	(0.08)
Lag 1		-0.25**	0.02	-0.07	-0.04	-0.03	-0.09**	-0.06	-0.08**
		(0.12)	(0.06)	(0.06)	(0.06)	(0.04)	(0.04)	(0.05)	(0.04)
Lag 2			-0.30**	-0.08	-0.13*	-0.09	-0.06	-0.10**	-0.05
			(0.11)	(0.05)	(0.07)	(0.06)	(0.05)	(0.04)	(0.05)
Lag 3				-0.22**	-0.09	-0.15*	-0.13*	-0.10	-0.15***
				(0.10)	(0.08)	(0.08)	(0.07)	(0.06)	(0.05)
Lag 4					-0.13	0.00	-0.06	-0.07	-0.08
					(0.08)	(0.06)	(0.06)	(0.07)	(0.05)
Lag 5						-0.12*	0.02	0.01	0.04
						(0.07)	(0.06)	(0.09)	(0.06)
Lag 6							-0.12	-0.07	-0.06
							(0.09)	(0.07)	(0.07)
Lag 7								-0.05	-0.08
								(0.10)	(0.05)
Lag 8									0.03
									(0.09)
Ln GDP per capita$_{c,y}$	0.70**	0.94***	1.00**	1.04**	1.09**	1.12**	1.13*	1.11*	1.07*
	(0.32)	(0.34)	(0.41)	(0.47)	(0.52)	(0.54)	(0.56)	(0.55)	(0.53)
Ln Population$_{c,y}$	0.41	0.89	0.85	0.79	0.83	0.78	0.76	0.64	0.49
	(1.30)	(1.11)	(1.13)	(1.18)	(1.24)	(1.22)	(1.20)	(1.17)	(1.16)
Temperature (°C)$_{c,y}$	-0.01	-0.03	-0.01	-0.02	-0.04	-0.05	-0.05*	-0.05*	-0.05***
	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.02)
Country and year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	775	728	682	638	598	564	534	504	475
Countries	39	39	38	35	32	29	29	29	27
R^2	0.55	0.67	0.68	0.68	0.67	0.68	0.68	0.69	0.70
Long-run price elasticity	-0.55***	-0.50***	-0.55***	-0.59***	-0.61***	-0.64***	-0.66***	-0.68***	-0.68***
Price elasticity from between estimate for same sub-sample	-1.26***	-1.68***	-0.86***	-0.99***	-1.00***	-0.79**	-0.77**	-0.78**	-0.70**

Notes: ***, **, and * indicate statistical significance at 1, 5, and 10%. Standard errors (in parentheses) are robust and clustered at the country level. The R^2s reflect the power of the explanatory variables, except the country fixed effects. Coefficients on constants and country and year fixed effects not reported. The results in column 1 are the same as column 4 of Table 2. The long-run price elasticity is the sum of the coefficients for each price term. Ln Land$_{c,y}$ is included in estimations that use the between estimator. The sample size reduces across the columns due to missing data on lagged price.

4. Reconciling the estimates with prior studies

Existing studies on natural gas demand typically examine a single country, and commonly report that demand for natural gas is price inelastic in both the short and long runs.[15] Balestra and Nerlove (1966), for example, obtained a long-run price elasticity of demand for natural gas in the United States of –0.6, similar to Berndt and Watkins' (1977) long-run estimate of –0.7 for household and commercial natural gas use in two Canadian provinces. Maddala et al. (1997) report estimates of the long-run price elasticity of household natural gas demand in the United States that vary from –0.2 to –1.4; Berkhout et al. (2004), Yoo et al. (2009), and Dagher (2012) use various specifications to report price elasticities of demand for natural gas of –0.2 for households in the Netherlands, South Korea, and Colorado; Payne et al. (2011) a long-run price elasticity of household natural gas demand in Illinois of –0.3; Alberini et al. (2011) a long-run price elasticity of natural gas demand of around –0.6 for household natural gas in the United States; and Wadud et al. (2011) a very inelastic response in Bangladesh. Some country-specific studies do, however, report that natural gas demand is price elastic. Yu et al. (2014), for example, pursue a static panel estimation of city-level residential natural gas demand in China, reporting a price elasticity of –1.4. Lin et al. (1987) report a long-run price elasticity of –1.2 for residences in the United States, and higher values for the commercial and industrial sectors. Our results are similar to their estimates.

There are other studies that have used international data. Brenton (1997) used expenditure and price data for 60 countries from the 1980 International Comparison Project, obtaining estimates of the price elasticity of natural gas use of –0.9 for middle-income countries. Brenton obtained more elastic estimates for low- and high-income countries, although with low precision. He estimated expenditure elasticities of natural gas use of +1 and above. Krichene (2002) used cointegration analysis on data aggregated for the world as a whole and reported a long-run price elasticity of –1.1 for 1973–1999, similar to our estimates using national data. Asche et al. (2008) used a shrinkage estimator for 12 European countries and reported an average long-run price elasticity of demand for natural gas of only –0.1, while Dilaver et al. (2014) found a long-run price elasticity of –0.2 for an aggregate of European countries. Anderson et al. (2011) used data for 11 industries in 13 OECD countries, reporting long-run price elasticities of natural gas demand of –0.1 to –0.6. Our estimates using more aggregate data for a larger sample of countries suggest that natural gas is more price elastic than this.

The International Monetary Fund (IMF)'s modelling of fossil fuel subsidies (Coady et al., 2015) uses a long-run price elasticity of natural gas demand of –0.25, sourced from Liu's (2004) study of 23 OECD countries over 1978–1999. Our higher estimates imply that the environmental benefits of natural gas subsidy reform may be larger than the IMF's work suggests (assuming concurrent subsidy reform for other fossil fuels, and/or Pigouvian taxes).

[15] See Al-Sahlawi (1989) for a review of early studies.

Prior estimates of the income elasticity of natural gas demand display a broad range. Many studies find that natural gas demand is income inelastic even in the long run (e.g. Berndt and Watkins, 1977; Yoo et al., 2009; Alberini et al., 2011), although Dilaver et al. (2014) and Asche et al. (2008), for example, report long-run income elasticities of +1.2 and +3 for Europe. Lin et al. (1987) report that natural gas demand in the United States is income elastic in the long run for the commercial and industrial sectors, but income inelastic for residences. Krichene (2002) reported a long-run income elasticity of +1.5 using globally-aggregated data, again similar to our estimates.

5. Conclusion

This study uses national data to estimate the long-run price and income elasticities of natural gas demand. We find that the aggregate long-run price elasticity is around –1.25, more elastic than reported by most prior papers with a sector-specific focus (e.g. Anderson et al., 2011). Similar results are obtained using either single-equation or IV estimation. We also find quite similar results for aggregates of natural gas use by industry and households, although the short-run price elasticity of household demand for natural gas appears likely to be small.

At the aggregate level, natural gas use appears to be more price sensitive than the demand for road-sector gasoline, for which estimates of the long-run price elasticity of demand are in the order of –0.2 to –0.6 (Havranek et al., 2012; Burke and Nishitateno, 2013; Burke, 2014; Arzaghi and Squalli, 2015). This makes sense, as there have been more substitution possibilities for natural gas in contexts such as electricity generation than have existed for road energy use. That price elasticities of demand for fossil fuels are negative implies that price-based approaches to mitigating negative externalities from fossil fuel use are indeed able to induce a reduction in consumption. The result also suggests that subsidy reform could lead to sizeable reductions in natural gas use and related emissions in countries that currently have below-cost natural gas prices. Subsidy reform for natural gas alone could induce substitution to other fossil fuels, but this would be less likely if subsidies for other fuels were reformed concurrently, and/or appropriate externality taxes applied.

Our estimates suggest that the long-run income elasticity of natural gas demand is +1 or above, higher than what Csereklyei et al. (2016) and Burke and Csereklyei (2016) report for the long-run income elasticity of aggregate energy use (+0.7). This is consistent with the observation that natural gas's share of the global energy mix often increases as economies grow (Burke, 2013). In addition to income growth, switching to natural gas is currently being spurred by the price-reducing effects of a supply-side boom in unconventional gas in the United States and elsewhere.

This study has an aggregate, long-run focus. There is scope for more studies using within-country data to examine micro-level factors affecting natural gas demand. Nevertheless, we believe that the macro-level elasticities in this paper will prove useful for modelling and other purposes.

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Appendix. Variable definitions

Natural gas consumption: Total primary use of natural gas, aggregated in terajoules. Natural gas is defined as gases occurring in underground deposits that consist mainly of methane. Natural gas may be in either liquefied or gaseous form and includes methane gas produced in association with crude oil or coal extraction. Source: IEA (2015a).

Natural gas consumption by industry: Total final use of natural gas by industry, aggregated in terajoules. Industry includes: iron and steel; chemical and petrochemical; non-ferrous metals; non-metallic minerals; transport equipment; machinery; mining and quarrying; food and tobacco; paper, pulp, and print; wood and wood products; construction; textile and leather; and non-specified. Source: IEA (2015a).

Natural gas consumption by households: Total final use of natural gas by households, aggregated in terajoules. Excludes transport. Source: IEA (2015a).

Natural gas price (average of industry and household prices; real): Simple mean of the average prices paid by (a) industry and (b) households, deflated by the US GDP deflator. Prices are the end-user price inclusive of taxes, measured in US$/MWh based on the gross calorific value of the gas. The price includes fixed charges. Source: IEA (2015c). Source of US GDP deflator: World Bank (2015).

Natural gas price (industry; real): The average natural gas price paid by industry, deflated by the US GDP deflator. The price is the average end-user price inclusive of taxes, measured in US$/MWh based on the gross calorific value of the gas. The price includes fixed charges. Source: IEA (2015c). Source of US GDP deflator: World Bank (2015).

Natural gas price (household; real): The average natural gas price paid by households, deflated by the US GDP deflator. The price is the average end-user price inclusive of taxes, measured in US$/MWh based on the gross calorific value of the gas. The price includes fixed charges. Source: IEA (2015c). Source of US GDP deflator: World Bank (2015).

Natural gas reserves per capita: Proved reserves of natural gas in the country and in other countries (distance-weighted) as of 1 January, in million cubic feet per capita. See Eq. (3) for how this variable was calculated. For some cases of missing reserves data for a country, values for an adjacent year were used. Source of natural gas reserves: U.S. Energy Information Administration (2015). Source of distance data: CEPII (2016).

GDP per capita: Expenditure-side real gross domestic product in chained purchasing power parity terms. Measured in million year-2005 US$ per capita. Source: Feenstra et al. (2015).

Population: Total population at mid-year, following the de-facto definition. Source: World Bank (2015). If missing, data from Feenstra et al. (2015) were used.

Land: Total area, excluding area under inland water bodies, national claims to continental shelf, and exclusive economic zones, in squared kilometers. Source: World Bank (2015).

Temperature (˚C): Temperature averaged over each country's land area and over the 12 months of the year. Source: Harris et al. (2014). Data version: CRU TS v3.22. See https://crudata.uea.ac.uk/cru/data/hrg/. For Chinese Taipei, a value of 22˚C was used (http://www.taiwan.climatemps.com/).

Gasoline price: Pump price of the most widely-sold grade of gasoline, in US$. Source: World Bank (2015).

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