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King Abdullah Petroleum Studies and Research Center

Quantifying Worldwide Demand Elasticities as a Policy Tool

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Key Points

This paper provides a comprehensive worldwide database of estimated elasticities for electricity and natural gas for households as a function of income, price, capital stocks and weather conditions.

Emerging economies show lower price elasticities than advanced economies as a result of limited physical capital availability and lock in effect pertaining to energy consumption.

Hot weather has a higher impact on energy demand in emerging economies than in advanced ones, as a result of higher efficiency and diversified technologically-advanced equipment.

We find that the energy demand elasticity to capital stock is positive implying that the rebound effect prevails over the substitution effect when it comes to the deployment of capital stock technologies.

For most countries, including former Soviet Union economies, natural gas is considered as an essential good while electricity is perceived, economically, as a luxury where its income elasticity is above unity.

Summary

Understanding how energy demand responds to prices changes is crucial for policymakers around the world. Elasticity is a quantitative measure of this response. This subject has been widely analyzed in empirical studies, but the quality of the results varies, leading to limited comparability across countries.

In this paper, we provide a new and more accurate approach to estimate aggregate energy demand elasticity for 117 countries. The model that we have developed provides a coherent and integrated empirical tool for policymakers to quantify how energy demand responds to policies. The model allows simultaneous variations of prices, income and capital stock or productive capacity, while including climate conditions as an uncontrollable factor.

Our approach is unique in accurately estimating demand response to prices by explicitly modeling a utility-maximizing rational behavior for consumers in each of the countries studied. This implies a better estimation of the energy demand function as it is computed using a structural model based on a simultaneous system of equations, thus avoiding potential econometric bias in the resulting parameters.

Our econometric estimation provides new refined quantitative evidence on the impact of changes in prices and income on energy demand. Specifically, we found that the aggregate energy elasticity to price has a world average of 0.19 and the electricity elasticity to price is between -0.10 and -0.20 for most countries, meaning that both energy and electricity have limited price elasticity. The study found that emerging economies have a lower energy demand price elasticities than advanced ones. In addition, the intra-fuel analysis shows that natural gas is generally perceived as more of an essential good than electricity, especially in less developed economies. This is partly due to the fact that natural gas is mostly used for essential needs such as heating and cooking.

We found that the demand elasticity for cooling needs is triple that of heating, which means more final energy is used for cooling than heating on a per capita level. Yet people in richer countries are rooted in their comfortable lifestyle when it comes to their heating needs, resulting in positive gas elasticity to heating degree days. This is aligned with the general observation that countries with natural gas endowments prefer to maximize its usage. These findings have welfare-improving policy implications, because appropriate policy strategies can help decision-makers to promote production efficiency and consumer welfare.

Policy Insight

Our work quantifies how consumer energy demand responds to changes in key variables, such as income, prices, capital stock availability and climate conditions. The calculated response factors are known as demand elasticities. Policymakers can use demand elasticities in many ways, including in designing efficient price policies and in setting fuel subsidy and taxation levels.

Public authorities alter the prices of goods in a number of ways. In some cases, they administer prices for an entire class of products or subject them to uniform taxes or subsidies. Tobacco and energy are typical of this first type of price control. In such cases, the demand elasticity is useful for assessing how consumption might change with prices: for example, increasing tobacco excise duties or raising gasoline prices.

In other instances, they focus on the price of only one particular good and leave the prices of others within that class to market forces. Bread and pharmaceuticals may provide examples of this second type of price control. Here, only the basic type of bread would be subject to a price cap to ensure that poor households could afford a basic need. In the case of pharmaceuticals, a basic class of active ingredient might be the target for policy action. All other types of bread and pharmaceuticals would have free prices, so overall demand would be the sum of the quantity consumed under the administered price plus the quantity consumed under the free market pricing regime.

Policy goals can also revolve around raising revenues through price taxation. In this case, the policy maker must know the associated demand elasticity to make accurate budget forecasts. The quantity consumed changes with price according to the demand elasticity, meaning that an increase in tax may result in lower consumption and hence lower-than-expected revenue. Very elastic behavior could have the contrarian effect of reducing government income. Quantifying distortions due to taxation can be a difficult task, hence the application of our elasticities can help in the development of better calibrated policies.

Another sensitive issue for policymakers is funding limitations and the associated efficiency-equity trade-off. Many pricing policies have a role in improving the living conditions of poor households, but usually impose a societal cost in terms of market inefficiency. The reverse is also true; when implementing policies to promote economic efficiency, the poorest in the society often get hurt.

At one level, the policy maker needs instruments to measure inefficiencies in the market caused by tax distortions or imperfections, such as externalities and non-competitive market behaviors. In this respect, demand elasticities are useful to construct the minimum distortion pricing policy (the so-called Ramsey pricing), a cornerstone of the efficiency-equity trade-off. On another level, the same policy maker needs to assess the economic impact of equitable intervention, like price subsidy to the poor and elderly. The maximum equitable solution is the other cornerstone of the efficiency-equity trade-off.

Our model of estimated demand elasticities can provide a quantitative assessment of policy interventions on energy prices, income and capital formation in the household sector. In addition, our model can quantify the effect on energy consumption of specific climate conditions across the world, allowing cross-country comparison net of the differences in natural climate conditions.

Background Review

Most previous studies are based on the single demand estimation, assuming a partial equilibrium viewpoint and neglecting the simultaneity of consumer decision processes (Hodge and Dahl, 2012; Labandeira, 2012). This approach is at variance with observed behavior, especially considering the complex relationships among consumer goods and services, as households optimize their consumption under a constrained budget.

Previously published works used weather conditions or capital stock as a regressor, or explanatory variable, in the estimation of a single energy demand function, typically as a production input at all aggregation levels. Their primary interest was usually the causal relationship between energy and GDP (Atalla & Hunt, 2015, Coers and Sanders, 2012; Filippini and Hunt, 2011; Lee and Mei-Se, 2010). Similar studies addressed residential electricity demand in a household production model (Flaig, 1990), the impact of energy efficiency (Hunt and Ryan, 2014) and the impact of weather on short-term and long-term residential demand.

However, the literature lacks analysis of simultaneous aggregate demand behavior, taking into account the complex impact of climatic conditions and capital stock on rational choices about energy.

In this study, we consider household behavior in 117 countries, representing more than 95% of world population and 97% of primary residential energy consumption, for the period 1978-2012. Households' energy expenditure and total energy consumption are modelled as the sum of residential electricity and gas consumption. The model assumes that all consumers in the market are cost minimizers, but still demand a diverse basket of goods. We further implement a multistage optimization process, which uses the minimum number of parameter requirements while remaining flexible in modeling complex demand behavior and acknowledging that both capital and climate conditions affect demand choices.

This research improves on existing literature in three ways. First, we improve upon the single equation approach in the energy and electricity market (e.g. Bernstein and Griffin, 2006 among others), taking into account work on consumers' energy demand, on informed electricity consumers, and on how demand reacts to climate (Faruqui et al., 2012; Schaffrin and Reiblin, 2015). Second, we present estimations of price and income elasticities of the household sector for the largest number of countries for which coherent data are available. Finally, we build on that by explicitly incorporating weather effects and capital stock in the demand system in a theoretical framework, making the elasticity values comparable across countries. To incorporate weather effects, we use a new dataset of specific measures of heating and cooling degree days (Atalla et al., 2015). For capital stock, we assume that energy is used for a variety of needs using capital equipment (e.g. residential appliances, industrial machinery and furnaces) that is predetermined by the goods allocation choice. In other words, we treat capital stocks as an exogenous variable in the estimation model.

Estimated Demand Elasticities

The model has two steps. In the first step, the consumer decides how to allocate spending between energy services (not including liquid transportation fuel) and other goods and services, referred to as the "composite good". This good includes, according to national accounts definition, all household expenditure related to food, shelter, clothing, healthcare and leisure, among other services. This decision takes into account the consumer's capital stock (in this case, the set of energy-using appliances and such) and the ambient climate conditions, measured in terms of heating and cooling degree days. In the second step, the consumer decides how to divide his allocation for energy between electricity and other energy products.

First model stage – energy as a whole

Tables 1-5 in the appendix show the representation of household demand behavior in terms of income and Marshallian price elasticities. The first modeling stage reflects logical results: the income elasticity for energy is well below unity, meaning that demand for energy rises more slowly than income, demonstrating that energy is a necessary good. The shares of energy and other goods and services in household consumption are available on request. Energy's share of household expenditure has been low recently, due to low prices.

The price elasticity estimates are all negative, meaning that demand for goods and services decreases as their price increases. Most of them are negative at the five percent significance level, which is statistically validated.

The average energy price elasticity across the world is -0.19. In our results, the price elasticity is higher (in absolute value) in OECD countries and lower in emerging countries, BRICS and OPEC, meaning that energy demand is more responsive to price changes in OECD countries. Brazil provides a notable exception with relatively higher elasticity.

Price elasticity for the "composite good" is around -0.9 to -1.0 for most countries, illustrating that a 1% increase in price translates into a 0.9% to 1% decrease in demand. This is a credible result for a large "composite good", which includes both basic goods such as food and specific goods such as services (see Tables 2 and 5).

The energy elasticity to the capital stock is positive, implying that an increase in capital formation, ceteris paribus, increases energy demand. This is an indirect confirmation that the rebound effect prevails over the substitution effect when it comes to the deployment of capital stock technologies.

Furthermore, the energy elasticity to weather variables are positive, implying that an increase in heating or cooling degree-days, ceteris paribus, increases energy demand. An important result is that the elasticity to cooling needs is about triple that of the elasticity for heating, meaning that energy demand increases three times more in response to a cooling degree day than it does in response to a heating degree day. This result is a potential quantification of the difference in energy efficiency of cooling vs. heating systems.

Second model stage – electricity and natural gas

Electricity and gas make up around 70% and 30% of energy expenditure in richer countries, respectively. The opposite is true for poorer and emerging countries.

Estimated Demand Elasticities

The second stage of the model illustrates plausible price elasticities with values below unity (in absolute value) for both electricity and gas, meaning that demand for both goods is inelastic. The conditional income elasticities show that natural gas is a necessity (with an income elasticity less than one) and electricity is a luxury good (with an income elasticity greater than one) (see Table 3). The categorization of natural gas as a necessity signifies its use for basic heating needs. Additionally, many emerging countries have access to inexpensive gas, particularly the former Eastern Bloc. The elasticity to capital stock is negative for electricity and positive for gas. These results imply that an increase in capital formation, ceteris paribus, stimulates efficiency in the case of electrical equipment (reducing electricity demand) and stimulates substitution of gas for possibly less efficient or more polluting energy sources, such as oil products or coal (increasing gas demand).

The elasticity values to weather variables have opposite effects for the two fuels. In the case of electricity, elasticity is positive to cooling degree days and negative to heating degree days. The reverse is true for gas. These results indicate that an increase in the requirement for heating, ceteris paribus, increases gas demand and decreases electricity demand. An increase in requirement for cooling increases electricity demand and decreases gas demand. This result is of great value as it provides an empirical measure of the specialization in the use of gas for heating and of electricity for air conditioning. Notice that in absolute terms the elasticity values to cooling are about triple the elasticity values to heating, reflecting the relative efficiency of heating and cooling with respect to degree days.

Conditional elasticities are calculated considering a balance between expenditures for energy and expenditures for other goods and services. Unconditional elasticities allow changes in the prices of other goods and services to change the amount spent on energy services. The unconditional elasticities confirm the general macro-economic consumption pattern. They are generally lower in absolute value than the conditional elasticities (Table 4). This finding shows the importance of two-stage modeling to correctly estimate the elasticity values for electricity and other energy goods. The unconditional elasticity of electricity is the correct measure of the consumer response to a change in the price of electricity, taking into account the whole preference structure of consumer behavior. Estimated values of electricity price elasticity are approximately -0.1 to -0.2 for most countries.

The estimated elasticities for electricity and natural gas are correlated to GDP per capita (see Figure A1). In particular, the price elasticity of electricity is increasing (in absolute value) vs GDP per capita, whereas the reverse is true for gas. This shows that richer countries have more options to change among alternative source of energy services.

Moreover, we find that the electricity elasticity to cooling degree days, although positive, is inversely correlated to GDP per capita. This shows that energy efficiency in cooling is more identifiable in higher income countries, meaning that better informed consumers of these economies have more money to spend on improving energy efficiency. Likewise, gas elasticity to heating degree days is positive and more so for colder and richer countries.

Conclusion and Policy Implications

Our analysis provides innovative worldwide estimates of price and income elasticities and a matrix of conditional and unconditional elasticities for electricity and other sources of energy services. Our main empirical finding is that on a global level, energy consumption is inelastic with a price elasticity of about -0.2, a result consistent with previous findings in literature based on static analysis.

In addition, our country-level approach provides a more precise map of the distribution of global elasticity behavior. We note the pattern of emerging economies showing lower price elasticities than advanced countries, with the exception of North America. Furthermore, we notice a difference between the perceived value of electricity and natural gas, with gas considered more of an essential good and electricity more of a luxury.

Another innovation of this paper is the estimation how weather effects energy demand. The results show that the cooling degree day elasticities are inversely correlated to per capita income, in the case of electricity consumption, reflecting greater cooling efficiency in advanced economies. Our model confirms that country specific elasticities are not constant through time and income levels.

Next Steps

This research implies that a more dynamic model needs to be developed to better understand the volatile effects associated with energy pricing. Decision makers must carefully account for how price and climate changes create feedback loops with demand behavior in order to design successful policies that maximize societal benefit.

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Data Appendix

Table A1. Consumption budget shares (*), 2010-2014.

Panel A – First and second stage allocation by countries and regions

	First Stage			Second Stage	
Region	**W1**	**W2**		**S1**	**S2**
OECD	0.94	0.06	**OECD**	0.60	0.40
N. America	0.96	0.04	**United States**	0.73	0.27
			Canada	0.62	0.38
Japan	0.91	0.09	**Japan**	0.60	0.40
Australia	0.96	0.04	**Australia**	0.80	0.20
European Union	0.93	0.07	**European Union**	0.56	0.44
BRICS	0.87	0.13			
Russia	0.96	0.04	**Russia**	0.70	0.30
China	0.83	0.17	**China**	0.33	0.67
India	0.89	0.11			
Brazil	0.93	0.07			
OPEC	0.93	0.07			
Iran	0.95	0.05	**Iran**	0.12	0.88
Venezuela	0.98	0.02	**Venezuela**	0.90	0.10
Saudi Arabia	0.99	0.01	**Algeria**	0.71	0.29
GCC	0.98	0.02			
N. Africa	0.93	0.07			
			Egypt	0.86	0.14
			Tunisia	0.66	0.34
S. America	0.94	0.06			
			Argentina	0.78	0.22
World	0.87	0.13	**Chile**	0.35	0.65

Source: KAPSARC analysis.

(*) W1= share of composite good, W2 = share of energy in the first stage allocation
S1= share of electricity, S2 = share of other energy sources in the second stage allocation

Table A2. Estimated elasticities – First stage, average 2005-2012 (*)

Areas	EL11	EL22	EL12	EL21	EL1Y	EL2Y	EL1K	EL2K	EL1C	EL2C	EL1H	EL2H
OECD	-0.99	-0.28	-0.05	-0.18	1.04	0.38	-0.01	0.10	0.00	0.08	-0.01	0.17
N. America	-0.97	-0.09	-0.06	-0.29	1.03	0.30	-0.02	0.22	0.00	0.01	0.00	0.02
Japan	-1.01	-0.58	-0.04	0.07	1.05	0.45	-0.02	0.09	0.00	0.03	0.00	0.04
Australia	-0.99	-0.41	-0.03	-0.21	1.02	0.48	0.00	0.03	-0.01	0.24	0.00	0.11
Eur. Union	-0.98	-0.33	-0.06	-0.12	1.05	0.38	0.00	0.04	-0.01	0.13	-0.03	0.36
BRICS	-0.99	-0.18	-0.13	-0.03	1.12	0.15	-0.07	0.29	-0.01	0.06	0.00	0.01
Brazil	-0.99	-0.45	-0.05	-0.04	1.04	0.41	-0.02	0.15	-0.02	0.29	0.00	0.01
Russia	-1.01	-0.08	-0.04	0.17	1.05	-0.07	0.00	-0.03	0.00	0.01	0.00	0.09
India	-0.99	-0.09	-0.12	-0.06	1.12	0.06	-0.06	0.37	-0.01	0.08	0.00	0.00
China	-0.98	-0.23	-0.16	-0.01	1.15	0.21	-0.09	0.29	0.00	0.01	0.00	0.01
OPEC	-0.95	-0.16	-0.14	-0.15	1.09	0.33	0.00	-0.01	-0.08	2.28	-0.01	0.35
Iran	-1.03	-0.52	-0.02	0.61	1.05	0.03	0.00	-0.05	-0.01	0.14	-0.01	0.16
Saudi Arabia	-1.01	-0.25	-0.01	0.42	1.02	-0.09	0.00	-0.02	-0.02	1.30	0.00	0.09
Venezuela	-0.95	-0.03	-0.06	-0.52	1.01	0.55	0.00	0.00	-0.05	2.10	0.00	0.00
GCC	-0.98	-0.22	-0.04	0.10	1.02	0.16	0.00	-0.01	-0.07	3.03	-0.01	0.32
N. Africa	-1.00	-0.27	-0.07	0.10	1.07	0.20	0.00	-0.01	-0.26	1.83	-0.02	0.32
South America	-0.98	-0.31	-0.05	-0.23	1.03	0.43	-0.01	0.09	-0.05	0.72	-0.02	0.24
World	-0.98	-0.19	-0.25	-0.04	1.24	0.18	-0.03	0.16	-0.38	0.75	-0.02	0.15

Source: KAPSARC analysis.

(*) First stage allocation: good [1] = composite good; good [2] = energy
EL [I] [J] = price elasticity of good [I] w.r.t. to price [J]
EL [I] Y = expenditure elasticity of good [I]
EL [I] K = capital stock elasticity of good [I]
EL [I] C = elasticity of good [I] w.r.t. cooling degree days
EL [I] H = elasticity of good [I] w.r.t. heating degree days
Some countries have a shorter average than the stated period. None has less than three years.

Table A3. Estimated conditional elasticities – Second stage, average 2005-2012 (*)

Region	EL11	EL22	EL12	EL21	EL1Y	EL2Y	EL1K	EL2K	EL1C	EL2C	EL1H	EL2H
OECD	-0.72	-0.24	-0.55	-0.29	1.31	0.49	-0.01	0.01	0.21	-0.28	-0.35	0.46
United States	-0.87	-0.09	-0.34	-0.25	1.21	0.34	0.00	0.00	0.02	-0.06	-0.02	0.07
Canada	-0.70	-0.25	-0.44	-0.39	1.17	0.60	0.00	0.01	0.05	-0.09	-0.33	0.62
Japan	-0.74	-0.17	-0.52	-0.27	1.29	0.41	-0.01	0.02	0.11	-0.18	-0.12	0.20
Australia	-0.63	-0.73	-0.18	-0.78	0.94	1.08	-0.01	0.05	0.31	-1.31	-0.12	0.54
Eur. Union	-0.69	-0.26	-0.66	-0.31	1.40	0.53	0.00	0.01	0.22	-0.31	-0.62	0.77
Russia	-0.86	0.04	-0.57	-0.24	1.48	0.10	-0.02	0.07	0.02	-0.04	-0.12	0.21
China	-0.63	-0.36	-1.36	-0.14	2.10	0.46	-0.31	0.18	0.05	-0.03	-0.04	0.02
Iran	-0.28	-0.53	-1.97	-0.08	2.24	0.62	0.00	0.00	0.76	-0.23	-0.36	0.13
Algeria	-0.80	-0.71	-0.19	-0.48	1.19	0.82	-0.01	0.04	0.57	-0.51	0.04	-0.57
Venezuela	-0.58	-1.29	-0.11	-2.94	0.74	3.91	0.00	0.04	0.49	-3.03	0.00	0.00
Egypt	-0.64	-2.26	-0.04	-0.40	0.93	1.39	-0.03	0.25	0.25	-1.46	0.00	-0.04
Tunisia	-0.63	-0.62	-0.31	-0.69	1.00	1.19	0.00	0.01	2.41	-2.71	-0.05	-0.44
Argentina	-0.72	-0.32	-0.24	-1.09	0.96	1.44	0.00	-0.01	0.29	-0.76	-0.11	0.15
Chile	-0.42	-0.50	-1.01	-0.21	1.42	0.72	0.00	0.00	0.59	-0.35	-3.01	1.93

Source: KAPSARC analysis.

(*) Second stage allocation: good [1] = electricity; good [2] = other energy sources
EL [I] [J] = price elasticity of good [I] w.r.t. to price [J]
EL [I] Y = expenditure elasticity of good [I]
EL [I] K = capital stock elasticity of good [I]
EL [I] C = elasticity of good [I] w.r.t. cooling degree days
EL [I] H = elasticity of good [I] w.r.t. heating degree days
Some countries have a shorter average than the stated period. None has less than three years.

For instance, EL11 is the own price elasticity of the electricity demand, EL12 is the cross-price elasticity of the electricity demand to the price of other good and so on. EL1Y is the expenditure elasticity of electricity demand and so on.

Table A4. Unconditional estimated elasticities – Second stage, average 2005-2012 (*)

Country	EL11	EL22	EL12	EL21	EL1C	EL2C	EL1H	EL2H
Algeria	-0.11	-0.47	0.72	-0.25	0.001	-0.003	0.64	-0.57
Armenia	-0.15	-1.16	-0.23	-0.43	-0.001	0.001	0.00	0.65
Australia	-0.19	-0.57	0.26	-0.62	-0.026	0.015	0.08	-0.32
Austria	-0.28	-0.22	-0.30	-0.16	-0.001	0.001	0.02	-0.02
Azerbaijan	-0.03	-0.01	0.10	-0.08	0.000	0.000	0.25	-0.41
Belarus	-0.02	-0.05	-0.11	0.06	0.000	0.000	0.08	-0.06
Belgium	-0.16	-0.18	-0.22	-0.09	-0.002	0.002	0.03	-0.04
Bolivia	-0.45	-0.24	0.03	-0.22	0.000	0.000	3.08	-2.93
Bosnia-Herzegovina	-0.02	-0.15	0.11	-1.36	0.000	0.000	3.13	-9.68
Canada	-0.03	-0.03	0.24	-0.17	-0.005	0.010	0.01	-0.02
Chile	-0.03	-0.15	-0.69	0.14	0.000	0.000	0.10	-0.06
China	-0.04	-0.12	-0.74	0.08	-0.090	0.055	0.01	0.00
Colombia	-0.01	-0.27	0.32	-0.49	-0.005	0.003	0.53	-1.28
Croatia	-0.04	-0.15	0.24	-0.70	0.000	0.000	0.82	-1.66
Czech Rep.	-0.10	-0.12	-0.16	-0.03	0.000	0.000	0.04	-0.03
Denmark	-0.22	-0.20	-0.57	-0.18	0.000	0.000	0.02	-0.02
Egypt	-0.07	-2.14	0.14	-0.28	0.014	-0.011	0.23	-1.28
Finland	-0.26	-0.31	0.11	-0.67	-0.001	0.001	0.03	-0.03
France	-0.22	-0.06	0.00	-0.11	0.008	-0.014	0.02	-0.01
Georgia	-0.18	-0.87	-0.21	0.83	0.000	0.000	0.28	-0.41
Germany	-0.10	-0.41	-0.32	-0.07	-0.020	0.010	0.00	-0.01
Greece	-0.25	-0.18	-0.19	-0.36	0.004	-0.005	0.93	-1.34
Hungary	-0.05	-0.10	0.01	-0.09	0.000	0.001	0.13	-0.14
Indonesia	-0.22	-0.02	0.30	-0.11	-0.024	0.028	0.12	-0.14
Iran	-0.34	-0.22	-1.77	-0.18	-0.017	0.026	0.13	-0.04
Ireland	-0.26	-0.35	-0.18	-0.24	-0.001	0.001	0.00	0.00
Italy	-0.42	-0.09	-0.29	-0.13	0.006	0.001	0.01	-0.01
Japan	-0.42	-0.10	-0.21	-0.20	-0.037	0.020	0.01	-0.01
Kazakhstan	-0.47	-0.46	-0.93	-0.55	-0.012	0.016	0.16	-0.14
Latvia	-0.06	-0.20	-0.21	0.13	0.000	0.000	0.43	-0.28
Lithuania	-0.16	-0.37	-0.28	-0.08	-0.001	0.001	0.35	-0.28
Mexico	-0.07	-0.15	-0.27	0.00	-0.025	0.028	0.24	-0.19
Moldova	-0.14	-0.41	-0.15	-0.03	0.000	0.000	3.07	-2.40
Netherlands	-0.08	-0.12	-0.26	-0.06	-0.004	0.005	0.02	-0.02
New Zealand	-0.20	-1.05	-0.16	-1.47	-0.001	0.000	0.04	-0.13
Pakistan	-0.15	-0.02	-0.29	0.00	-0.011	0.011	0.57	-0.38
Portugal	-0.31	-0.35	-0.02	-0.80	-0.001	0.001	0.16	-0.42
Slovakia	-0.11	-0.23	-0.07	-0.19	0.000	0.001	0.28	-0.36
South Korea	-0.05	-0.21	-0.03	-0.11	-0.015	0.024	0.02	-0.02
Spain	-0.20	-0.28	0.17	-0.48	-0.006	0.021	0.04	-0.11
Sweden	-0.20	-0.18	0.02	-0.35	-0.001	0.002	0.02	-0.01
Switzerland	-0.12	-0.25	-0.33	-0.18	0.001	-0.001	0.03	-0.02
Turkey	-0.16	-0.07	-0.06	-0.10	-0.034	0.020	0.06	-0.07
Ukraine	-0.01	-0.08	-0.54	0.11	0.003	-0.003	0.04	-0.02
United Kingdom	-0.15	-0.04	0.04	-0.15	-0.055	0.020	0.00	0.00
United States	-0.03	-0.61	0.49	-0.16	-0.011	0.028	0.00	-0.01

Source: KAPSARC analysis.

(*) Second stage allocation: good [1] = electricity; good [2] = other energy sources
EL [I] [J] = price elasticity of good [I] w.r.t. to price [J]. EL [I] C = elasticity of good [I] w.r.t. cooling degree days
EL [I] H = elasticity of good [I] w.r.t. heating degree days

Table A5. Estimated country elasticities - first stage - averages 2005-2012 (Composite good and energy)

Country	EL11	EL22	EL12	EL21	EL1Y	EL2Y
Albania	-0.96	-0.38	-0.10	-0.08	1.07	0.43
Algeria	-1.00	-0.06	-0.02	-0.11	1.02	0.20
Angola	-0.99	-0.01	-0.15	-0.17	1.14	0.17
Argentina	-0.99	-0.27	-0.03	-0.44	1.03	0.14
Armenia	-1.01	-0.84	-0.02	0.36	1.04	0.26
Australia	-0.99	-0.41	-0.03	-0.21	1.02	0.48
Austria	-0.99	-0.49	-0.05	0.01	1.05	0.42
Azerbaijan	-0.98	-0.01	-0.07	-0.18	1.06	0.19
Bahrain	-0.97	-0.21	-0.08	-0.21	1.05	0.39
Bangladesh	-1.00	-0.14	-0.03	0.06	1.03	0.13
Belarus	-0.98	-0.01	-0.11	-0.11	1.09	0.13
Belgium	-0.99	-0.36	-0.07	-0.06	1.06	0.35
Benin	-1.16	-0.08	-1.20	-0.01	2.37	0.09
Bolivia	-0.96	-0.18	-0.09	-0.19	1.05	0.33
Bosnia-Herz.	-0.93	-0.06	-0.09	-0.56	1.02	0.62
Brazil	-0.99	-0.45	-0.05	-0.04	1.04	0.41
Bulgaria	-0.96	-0.02	-0.10	-0.33	1.06	0.35
Burkina Faso	-1.73	-0.09	-2.92	-0.01	4.66	0.10
Cambodia	-1.12	-0.47	-0.44	0.34	1.58	0.09
Cameroon	-1.03	-0.18	-1.01	0.08	2.05	0.10
Canada	-0.84	-0.05	-0.21	-0.20	1.05	0.21
Chile	-0.97	-0.25	-0.08	-0.17	1.06	0.38
China	-0.98	-0.23	-0.16	-0.01	1.15	0.21
Colombia	-0.97	-0.11	-0.04	-0.54	1.01	0.62
Congo DR	-1.02	-0.08	-0.85	0.05	1.90	-0.03
Costa Rica	-0.46	-0.09	-0.54	-0.73	1.00	0.87
Cote d'Ivoire	-1.10	-0.16	-0.61	0.05	1.72	0.10
Croatia	-0.89	-0.05	-0.14	-0.41	1.04	0.46
Cuba	-0.96	-0.03	-0.03	-1.13	0.99	1.16
Cyprus	-0.99	-0.63	-0.01	-0.19	1.01	0.77
Czech Rep.	-0.98	-0.18	-0.11	-0.08	1.10	0.23
Denmark	-0.96	-0.51	-0.09	-0.10	1.05	0.59
Dom. Rep.	-0.98	-0.49	-0.04	-0.19	1.02	0.64
Ecuador	-0.97	-0.28	-0.04	-0.34	1.02	0.57
Egypt	-1.01	-0.30	-0.01	0.31	1.02	0.09
El Salvador	-0.96	-0.62	-0.09	0.12	1.06	0.44
Estonia	-0.48	-0.05	-0.61	-0.35	1.08	0.36
Ethiopia	-0.98	-0.07	-0.88	0.04	1.85	0.05

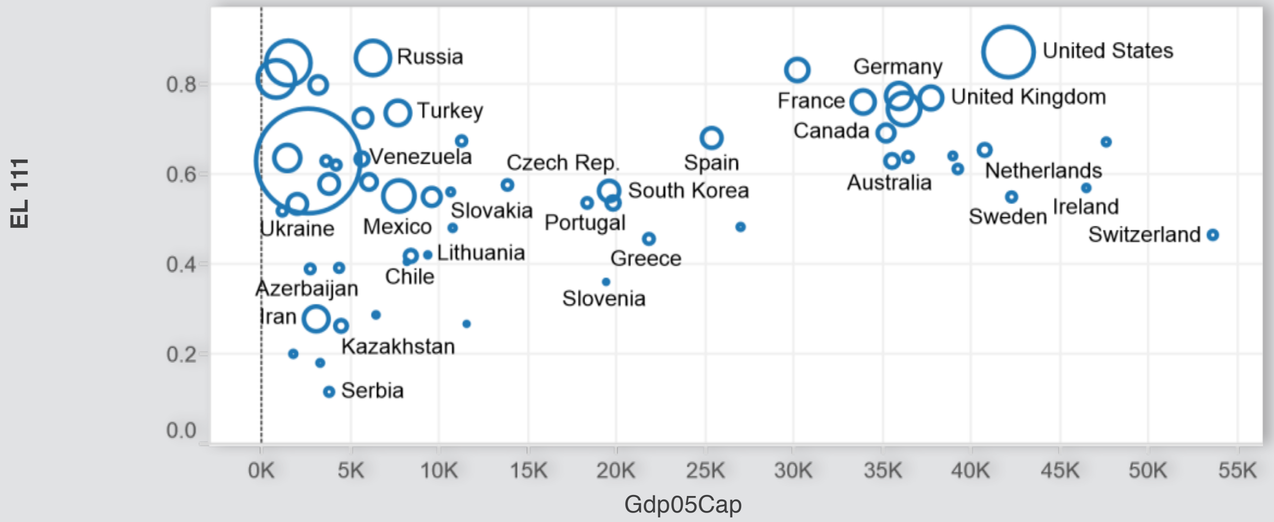
Data Appendix

Country	EL11	EL22	EL12	EL21	EL1Y	EL2Y
Finland	-1.00	-0.45	-0.06	0.03	1.07	0.37
France	-0.99	-0.26	-0.05	-0.14	1.05	0.32
Gabon	-1.20	-0.45	-0.51	0.32	1.72	0.10
Georgia	-1.00	-0.39	-0.10	0.10	1.11	0.23
Germany	-0.98	-0.29	-0.09	-0.09	1.07	0.34
Ghana	-1.02	-0.13	-0.43	0.03	1.45	0.08
Greece	-0.99	-0.53	-0.03	-0.09	1.03	0.53
Guatemala	-1.06	-0.26	-0.21	0.06	1.28	0.17
Haiti	-0.91	-0.04	-0.40	-0.11	1.31	0.15
Honduras	-0.98	-0.23	-0.18	0.01	1.17	0.19
Hungary	-0.98	-0.15	-0.11	-0.10	1.09	0.23
India	-0.99	-0.09	-0.12	-0.06	1.12	0.06
Indonesia	-0.99	-0.07	-0.13	-0.12	1.13	0.04
Iran	-1.03	-0.52	-0.02	0.61	1.05	0.03
Ireland	-0.99	-0.54	-0.04	-0.07	1.03	0.55
Italy	-1.00	-0.50	-0.04	0.01	1.04	0.38
Japan	-1.01	-0.58	-0.04	0.07	1.05	0.45
Jordan	-0.96	-0.10	-0.07	-0.37	1.04	0.46
Kazakhstan	-1.01	-0.53	0.00	0.24	1.00	0.58
Kenya	-0.67	-0.01	-6.01	-0.06	6.65	0.08
Kuwait	-0.99	-0.38	-0.01	0.23	1.01	0.27
Kyrgyz Rep.	-1.00	-0.42	-0.03	-0.38	1.03	0.74
Latvia	-0.94	-0.09	-0.16	-0.20	1.10	0.28
Lebanon	-0.97	-0.20	-0.03	-0.86	1.00	0.99
Libya	-0.95	-0.03	-0.06	-0.37	1.01	0.43
Lithuania	-1.04	-0.51	-0.02	0.15	1.07	0.28
Luxembourg	-0.94	-0.16	-0.08	-0.46	1.02	0.61
Malaysia	-0.99	-0.22	-0.06	-0.15	1.05	0.31
Malta	-1.05	-0.37	0.07	-0.85	0.98	1.19
Mauritania	-0.52	-0.11	-0.55	-0.34	1.06	0.46
Mexico	-0.98	-0.21	-0.03	-0.52	1.01	0.64
Moldova	-0.89	-0.21	-0.20	-0.05	1.09	0.22
Mongolia	-0.88	-0.21	-0.27	0.01	1.16	0.18
Morocco	-1.00	-0.65	-0.04	0.12	1.04	0.44
Mozambique	-0.65	-0.02	-1.07	-0.06	1.72	0.08
Netherlands	-0.98	-0.26	-0.07	-0.17	1.05	0.38
New Zealand	-0.97	-0.48	-0.04	-0.30	1.01	0.72
Nicaragua	-0.63	-0.07	-0.63	-0.16	1.26	0.23
Niger	-0.87	-0.09	-1.30	-0.04	2.18	0.12
Nigeria	-0.81	-0.02	-0.84	-0.02	1.65	0.06

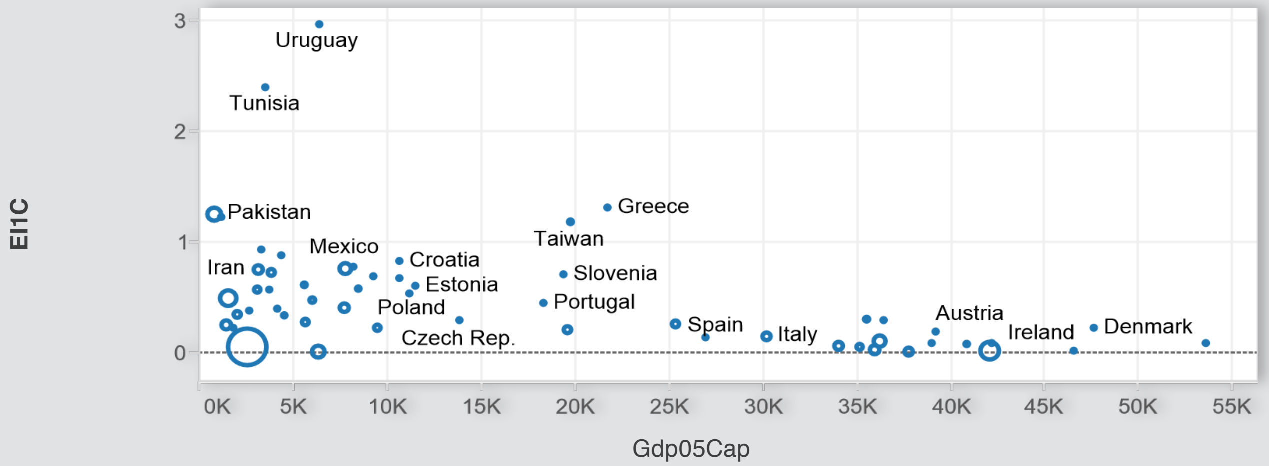
Country	EL11	EL22	EL12	EL21	EL1Y	EL2Y
Norway	-0.98	-0.48	-0.04	-0.13	1.03	0.52
Oman	-0.98	-0.17	-0.04	-0.40	1.02	0.44
Pakistan	-1.01	-0.15	-0.06	0.09	1.06	0.11
Panama	-0.97	-0.29	-0.09	-0.19	1.06	0.45
Paraguay	-0.93	-0.12	-0.14	-0.19	1.08	0.29
Peru	-0.98	-0.09	-0.05	-0.45	1.03	0.53
Philippines	-0.95	-0.15	-0.15	-0.16	1.10	0.30
Poland	-0.97	-0.14	-0.12	-0.11	1.10	0.23
Portugal	-0.99	-0.61	-0.03	-0.07	1.03	0.62
Qatar	-0.81	-0.06	-0.19	-0.68	1.00	0.80
Romania	-0.98	-0.01	-0.05	-0.37	1.03	0.38
Russia	-1.01	-0.08	-0.04	0.17	1.05	-0.07
Rwanda	-0.70	-0.25	-2.96	0.15	3.69	0.09
Saudi Arabia	-1.01	-0.25	-0.01	0.42	1.02	-0.09
Senegal	-0.89	-0.05	-0.38	-0.20	1.27	0.25
Serbia	-0.87	-0.01	-0.17	-0.36	1.04	0.39
Slovakia	-0.99	-0.39	-0.06	0.01	1.06	0.31
Slovenia	-0.93	-0.02	-0.12	-0.44	1.05	0.46
South Africa	-1.00	-0.01	-0.06	-0.21	1.06	0.05
South Korea	-1.00	-0.25	-0.05	-0.07	1.06	0.20
Spain	-1.00	-0.59	-0.03	-0.01	1.03	0.50
Sri Lanka	-0.95	-0.07	-0.21	-0.14	1.16	0.21
Sudan	-1.00	-0.15	-0.29	0.00	1.30	0.11
Sweden	-0.99	-0.39	-0.08	-0.04	1.07	0.39
Switzerland	-0.98	-0.56	-0.04	-0.10	1.02	0.55
Syria	-1.01	-0.33	-0.01	0.07	1.01	0.40
Tajikistan	-1.00	-1.12	0.02	-0.05	0.98	2.01
Tanzania	-0.59	-0.16	-7.67	2.64	8.24	-2.71
Thailand	-1.01	-0.28	-0.08	0.03	1.09	0.18
Tunisia	-0.95	-0.11	-0.10	-0.29	1.05	0.39
Turkey	-0.99	-0.21	-0.05	-0.14	1.04	0.22
Ukraine	-1.01	-0.11	-0.04	0.19	1.05	-0.05
U.A.E.	-0.91	-0.11	-0.10	-0.67	1.01	0.70
U.K.	-0.99	-0.27	-0.04	-0.25	1.03	0.41
United States	-0.99	-0.09	-0.04	-0.30	1.03	0.31
Uruguay	-0.92	-0.04	-0.11	-0.51	1.03	0.55
Venezuela	-0.95	-0.03	-0.06	-0.52	1.01	0.55
Vietnam	-1.04	-0.01	-0.13	-0.12	1.17	0.13
Yemen	-0.94	-0.12	-0.06	-0.59	1.01	0.68

Source: KAPSARC analysis.

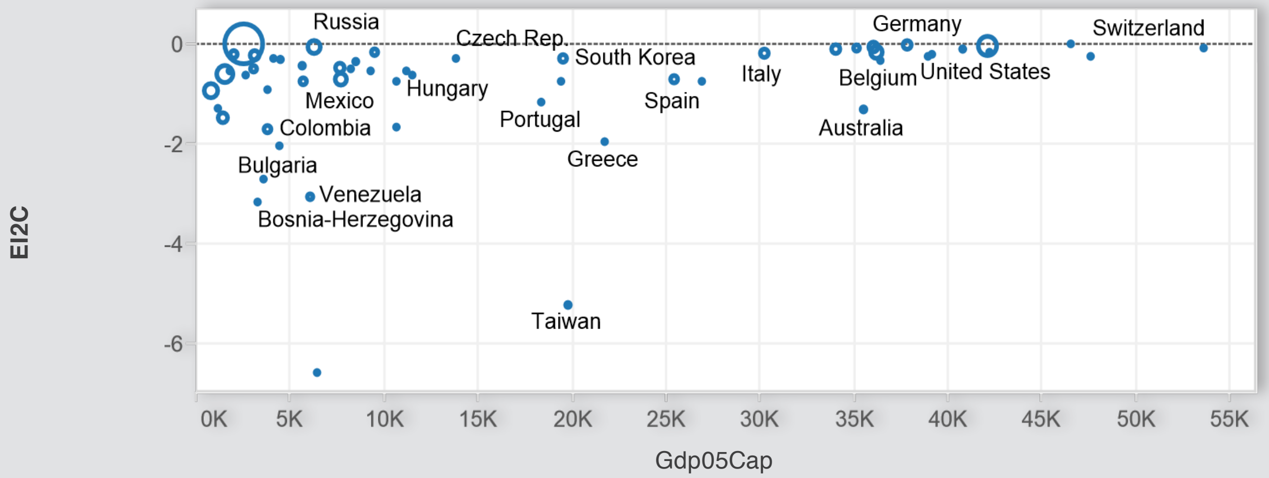
Second stage price elasticity of electricity



Second stage electricity demand elasticity to cooling degree days



Second stage "other energy" demand elasticity to cooling degree days



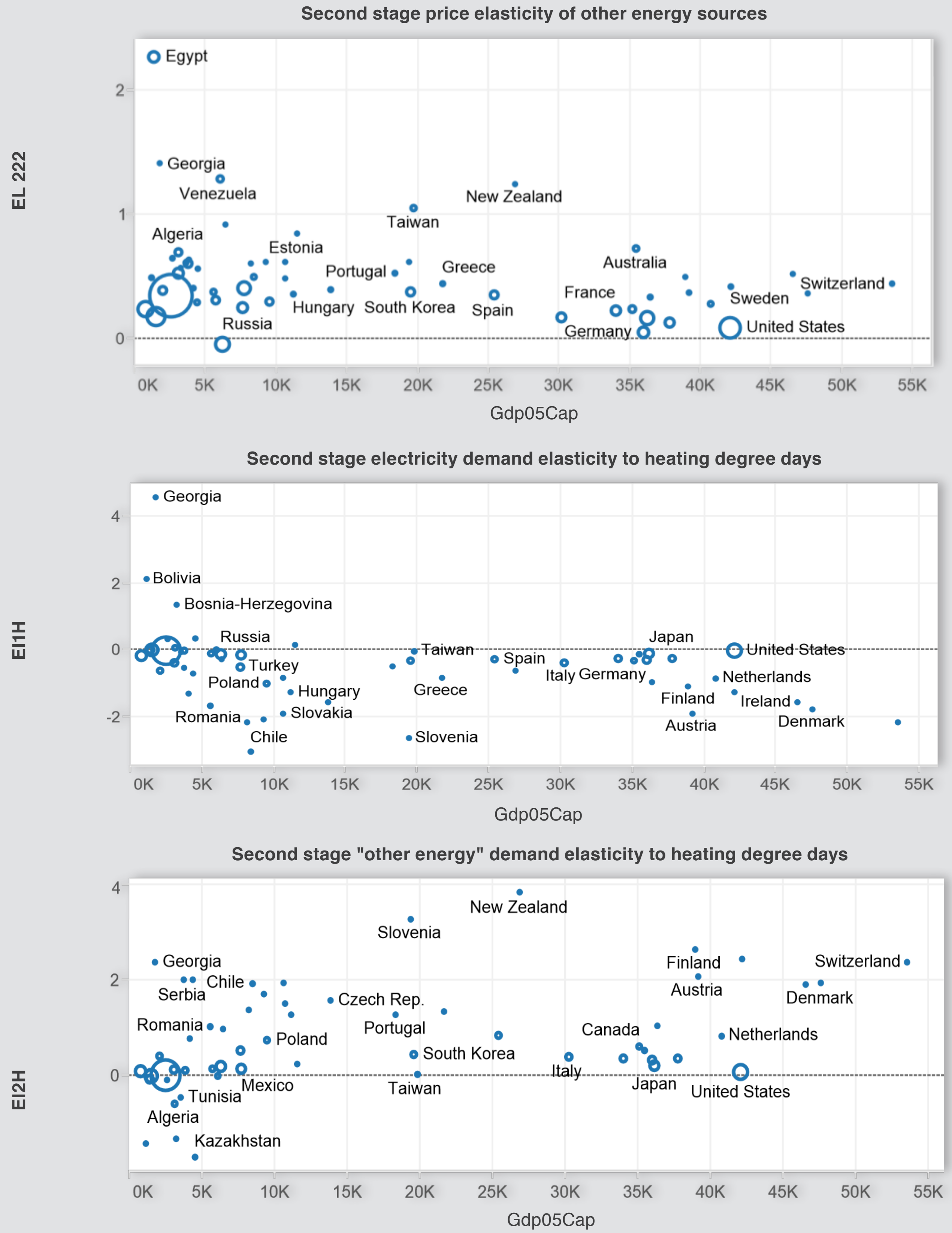


Figure A1. Second stage elasticities and GDP per capita – average 2005-2012.

Source: KAPSARC analysis.

Technical Appendix

Economic theory

We adopt a unifying cost minimization approach to model consumption demand, assuming that the agent making the choice is representative of the country aggregate behavior.

Using duality approach, we assume the existence of a multi-stage cost function for the consumption bundle (see Figure 3 below).The multi-stage model allows parsimonious parameterization without sacrificing empirical flexibility while reflecting a theoretically plausible multi-stage allocation process.

In the first stage, a representative consumer decides on how to allocate income to consume between energy e and a “composite good” y (the remainder of other goods and services demanded by our agents). The allocation is conditional on a predetermined variable, for which there is no explicit preference in the model (Browning and Meghir, 1991), and which we label Z with its price p_z.

This initial perception would assume a fixed capital stock, which can use energy as an input to provide various services to the household. It is obvious to assume that the embodied technology in Z conditions is the current choice of e, so that omission of this determinant in the model risks to bias the empirical results (Neary, 1980; Deaton and Muellbauer, 1981). In other words, a newer, more technologically advanced equipment consumes, in theory, less energy to render the same utility.

We show that specific household consumption is also dependent on specific weather conditions, which we label as Φ.

In the first stage, we model consumption variation as a mathematical function that depends on prices of energy and of the composite good (p_e, p_y), total utility U, the capital stock Z and weather conditions Φ, which are country specific (we omit here the country subscript for the sake of clarity):

$$C=C(p_e,p_y,Z, \Phi, U) = \min [\, p_e\, e + py\, y \mid U(e,y,Z, \Phi) \,] \quad (1)$$

We label consumption at the first level “group demand”, i.e. consumers demand quantities of the composite good and of energy, on the basis of corresponding “group prices”.

Secondly, the model depicts the choice of the agent at the second level. We pursue the analysis only within the energy group. In other words, given the previous choice, in the second stage, agents allocate demand among different types of energy, which we label as “elementary demand”. Demand quantity and demand vectors are (e_1,, e_m), for m elementary energy goods within the group demand e. In this paper, we focus on two elementary energy goods ($m=2$): residential electricity e_1 and commercial electricity e_2, which depend on the prices p_{e1} p_{e2} within the group.

In the second stage, with appropriate separability assumptions, we postulate a conditional cost function c_e for total group good energy e with utility U_e, from which to recover elementary energy demand functions which depend on energy prices:

$$Ce = Ce(pe1, pe2, \Phi, Ue) \quad (2)$$

The economic theory allows us to define the general mathematical formula for the demand function:

$$g_k = g_k(p_y, p_e, Z, \Phi, C \qquad \text{where } k= y, e \quad (3)$$

$$e_j = e_j(p_{e1}, p_{e2}, \Phi, Ce\ ,) \qquad \text{where } j= 1,2 \quad (4)$$

Eq. (3) defines group demand functions g_k for $k=[y,$

e], or g_y is group quantity for composite good and g_e is group quantity for energy. Eq. (4) defines the elementary demand functions within each group, defined as e_1, e_2, for the energy goods belonging to group g_e.

Let us further clarify that consumer behavior is completely characterized by eqs. (1) and (3) in the first stage and by eqs. (2) and (4) in the second stage.

These functions allow the assumption that agents exhibit some degree of substitutability or complementarity among various consumption goods and particularly for energy and electricity. In the case of electricity this can happen because facing different price signals (Wolak, 2011), consumers may decide to change certain activities that are alternatives to electricity usage (this gives rise to substitutability), such as house caring activities or usage of domestic appliances, e.g., hand washing instead of machine washing and so on. Alternatively, consumers can decide to change a complex activity in response to electricity price (this gives rise to complementarity), such as decisions to switch on air conditioners and stay indoors, more cooking, more TV watching and so on. It is important to incorporate the observation that individual consumers can and will optimize their behavior.

Consequently, we model aggregate behavior in our countries with equations (3) and (4), from which it is simple to estimate and compute elasticity of demand for each good, with respect to all prices and total expenditure, i.e. own price elasticity, cross price elasticity and expenditure elasticity. More precisely, in a multi-stage model we can compute both conditional and unconditional elasticities. We denote expenditure elasticities with η and price elasticities with ε.

Conditional elasticities are computed with fixed group expenditures. However, in reality, a price change in the second stage will also have an effect on the expenditure allocation in the first stage. For example, within the group quantity g_y, consider that food is one of the elementary goods and consider a change in the price of food: p_f. This obviously has an effect on the elementary demand for food y_f but also on the energy group demand g_e. Therefore, there is an effect on the group expenditure g_e, exerting in this way an additional effect via change in g_e, for instance, on the elementary demand function for residential electricity e_r. These effects are unconditional elasticities. Advanced details of the computation of conditional elasticities of the mathematical model can be found in section 1 of Appendix A.

The complete structure of the model is summarized in Fig.A3 where each box symbolizes a stage in the decision process of the consumer.

Derivation of the demand functions

Duality theory allows us to define indirect utility/production functions V() depending on prices and total cost obtained by inverting equations (1) and (2), under the assumption of indirect separability (e.g. Caves and Christensen, 1980 and Edgerton, 1997):

$$U=V(p_e, p_y, Z, \Phi, C) \tag{5}$$

$$Ue=V((p_{e1}, p_{e2}, \Phi, Ce) \tag{6}$$

Then we apply Roy's Identity to recover Marshallian demand functions, obtaining the dual demand functions defined in the text as eqs. (3) and (4). It should be stressed that this theoretical framework allows disaggregated private consumption categories to exert substitutability or complementarity effects on the demand for energy.

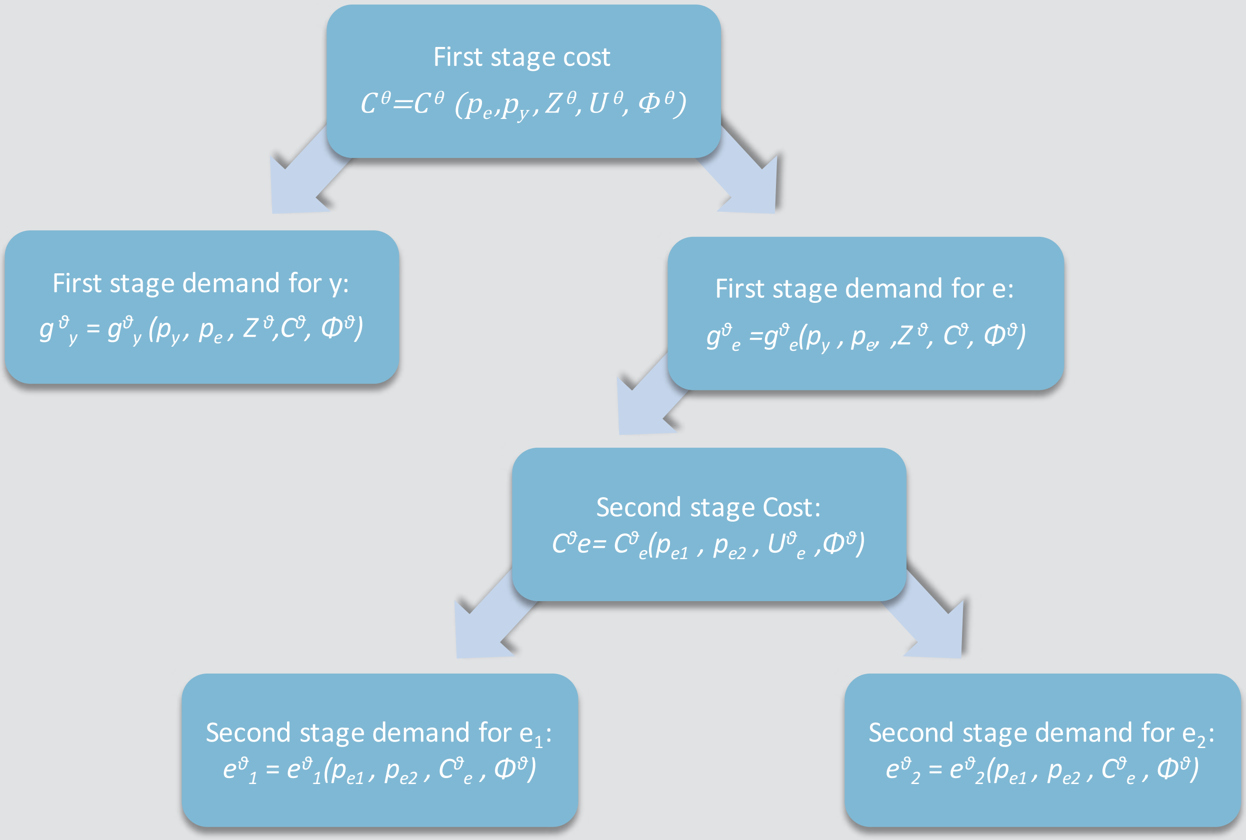


Figure A3. Multi-stage demand system for each country.

It should be stressed that this theoretical framework allows disaggregated private consumption categories to exert substitutability or complementarity effects on the demand for energy.

Source: KAPSARC analysis.

Derivation of conditional elasticities for the first and second stage models

We compute conditional expenditure and price elasticities, at the first stage, as:

$$\eta k = (\partial g_k/\partial C)(C/g_k) \tag{7}$$

$$\varepsilon(k)(s) = (\partial g_k/\partial p_s)(p_s/G_k) \tag{8}$$

for $\forall\ k,s \in [y,e]$.

and at the second stage, as:

$$\eta_{i(k)} = (\partial e_{i(k)}/\partial Ck)(C_k/e_{i(k)}) \tag{9}$$

$$\varepsilon_{ij(k)} = (\partial e_{i(k)}/\partial p_{j(k)})(p_{j(k)}/e_{i(k)}) \tag{10}$$

where $e_{i(k)}$ is the quantity and $p_{j(k)}$ is the price of elementary good in the group k: $i \in k$, *for* $\forall\ i,j \in [k]$ and $k = [e]$.

Subsequently, we recover unconditional elasticities from conditional ones (Edgerton, 1997; Deaton and Muellbauer, 1980) as:

$$\eta_i = \eta_{i(k)}\ \eta_k \tag{11}$$

$$\varepsilon_{ij} = \delta_{ks}\ \varepsilon_{ij(k)} + \eta_{i(k)}\ w_{i(k)}\ (\delta_{ks} + \varepsilon_{(k)(s)}) \tag{12}$$

where δ_{ks} is the Kronecker delta and $w_{i(k)}$ is the budget share of good i in group k.

The generality of the multi-stage approach can be appreciated, observing that in equation (12) the unconditional price elasticity depends on the conditional value plus a term involving the budget share and the difference from unity of the group price elasticity. This implies that elasticity values of equations (9) and (11) can differ and they can show values at above or below unity, i.e. elementary demands can be normal goods within a group but overall luxury goods (and vice versa). Equations (10) and (12) are not restricted to have the same sign implying that elementary demands can be conditional substitutes but unconditional complements (and vice versa).

In the GAI specification, the endogenous variables are the goods quantities. The exogenous variables are the logarithm price deflators of the goods and the real per capita total expenditure, obtained as the logarithm of the ratio of total per capita expenditure C and a general price index P, which is approximated using the Stone formula (Deaton, Meullbauer, 1980). In addition, there are the capital stock Z and the weather effect variables Φ.

Overview of the estimation results

We estimate the demand functions at the first stage and at the second stage in the period 1978-2012, using a specific empirical parametrization defined as General Almost Ideal (GAI), as explained by equations 13-15 and 16-18. Available data allows us to estimate demand equations for 117 countries in the first stage and for 46 countries in the second stage. Detailed description of the data can be found in section 5 below.

We use preliminary OLS estimated parameters as starting values for estimating the simultaneous equations system (Barten, 1969) as a seemingly unrelated equations regression model (SUR).

We use Full Information Maximum Likelihood (FIML) estimation technique, switching between the outer product of the scores and the Hessian to calculate the Fisher Information.

We have estimated the general model GAI, which includes the stock and the weather effect variables and performed diagnostic testing to provide confidence in the empirical results. In addition, we have imposed and tested six restrictions that are in the general model.

The estimated parameters of the general form are used to study the main characteristics of consumer preferences and the implications for fiscal policy.

Data description and econometric estimation

In this application we specify a demand system for 117 countries going back to the period 1978-2012. We constructed a homogeneous data bank for these countries for all variables. GDP and household consumption expenditure in real terms and GDP and consumption deflators are computed, as much as possible, according to the NIA (National Income Accounts) international guidelines. Household sectors include residential and commercial final energy usage.

Total final energy consumption, electricity and gas quantities, prices and exchange rates are computed taking specific information from national statistical sources in addition of energy balances (IEA, 2014; Enerdata 2015 and Thomson's Reuters DataStream). All prices are computed in constant 2005 dollars per tons of oil equivalent (toe) using World Bank's GDP deflator. A weighted average of various energy prices was generated in order to account for the price component of the aggregate energy consumption in the total household final consumption expenditure. In some very limited cases, mainly emerging economies, we also relied on local online publications (newspapers and magazines) to report changes in energy prices due to regulatory change in the administration of prices.

Capital stock variables are computed as index values, considering the aggregated time series of internet penetration, cellular phones diffusion and other proxies, scaled by the population size of the country. Climate variables are computed according to the original methodology explained in Atalla et al. (2015). Missing climate data for Cyprus, Malta, Luxembourg, Oman and Qatar were generated using Wolfram Alfa online computational platform. No population weighting was done for these countries as their small surfaces prevents large climatic changes.

The initial dataset included 186 countries for the period 1978-2012. Due to data limitations, we disregarded some countries while others were retained with a shorter time span. However, no country was reported having fewer than eight consecutive observations with 70+ countries having more than 20 observations. In this paper, our current definition of OECD excludes Iceland and Israel. OPEC excludes Iraq while South and Central America exclude the Guyanas and some Caribbean islands.

This leads to a matrix with a total of 2007 usable observations for our current estimation out of an original dataset of 8370 observations.

The descriptive statistics of budget shares in the allocation models, namely, the composite good and energy consumption in the first stage and the electricity and the gas consumption at the second stage are shown in table 1. We expect that the increased purchasing power would be devoted mostly to the consumption of goods other than basic needs like food and energy. Indeed, this stylized fact of previous country studies is confirmed. Notice that the energy share in total household consumption expenditure is 6% in the OECD area, 4% in the US and 7% in the EU. It is lower in the GCC countries (2%) and in particular in Saudi Arabia is 1% due to the price subsidization of electricity in that region. It is higher in China, around 17%. Other studies on China report the energy share only for urban residents, around 7% (Cao et al., 2014). Considering that the disposable income in the rural area is less than half of the urban income, it is conceivable that the average energy share in the whole country is higher according to our estimates. In general, the patterns of energy constitute a relatively small and fluctuating component of income allocation.

The weather variable accurately measures the heating degree days and cooling degree days for each country.

In order to find the best model, we perform different econometric specifications that includes a multi-stage parametric functional form of demand functions to estimate and test empirical price and income parameters of consumption demand, which complies with consumer theory restrictions, i.e., adding up, symmetry, homogeneity and heterogeneous consumer exact aggregation constraints.

Notice that this approach is different from the prevailing literature on energy demand (e.g. Labandeira et al., 2012). Many papers use simple linear specifications for the demand function, even if such function cannot be recovered in the framework of utility maximization.

In this paper, we assume a simple and flexible functional form for consumer preferences allowing for exact aggregation: the Generalized Almost Ideal demand system, GAI (Bollino, 1987). This system is a generalization of the original Deaton and

Muellbauer (1980) Almost Ideal (AI) system. The main feature of GAI is the introduction of committed quantities, which are intercept parameters capturing the exogenous quantity not depending on prices and expenditure. This is a realistic framework, insofar as consumers decide to buy a fixed quantity for each good (the committed quantity) and then allocate the supernumerary expenditure (i.e. the disposable income remaining after the purchase of the committed quantities) as a function of prices and supernumerary expenditures.

Committed quantities are useful in the econometric estimation of both time series and cross sectional data, because they allow Engel curves that are not forced to pass through the origin. In addition, committed quantities can vary with specific data characteristics, but they also allow demand functions to maintain all theoretical properties, thus allowing the introduction of the climate effect into the demand system in a simple and elegant way, as discussed below.

In addition, in our multi-stage framework, committed quantities at the second stage represent the exogenous quantities under the null hypothesis of no price and expenditure response of the elementary demand functions. Therefore, committed quantities are crucial to test the empirical significance of the multi-stage model.

At the first stage, eq. (5) is parametrized as:

$$g_k = f_k + C^*/p_k \ [\alpha_k + \textstyle\sum_s \beta_{ks} \ ln(p_s) + \gamma_c \ ln(C^*/P^*) + \zeta_k Z \quad (13)$$

where $k=y,e$ and f_k are committed quantity parameters, α_k are constants, β_{ks} are price coefficients, γ_k are total expenditure coefficient, ζ_k are capital stock coefficients, φ_k are weather coefficients,and w_k are group budget shares.

We define C* as the supernumerary expenditure:

$$C^* = c - (\textstyle\sum_s f_s \, p_s) \quad (14)$$

We define P* a price aggregator (Stone index):

$$P^* = \textstyle\sum_s w_s \ ln(p_s) \quad (15)$$

Eqs. (12)-(15) show the two group demand functions for composite good and energy. With adding up homogeneity and symmetry restrictions, there are 7 structural parameters to be estimated. Similarly, at the second stage, we parameterize elementary demand functions within the energy group. For the demand system of energy, we have:

$$e_i = f_i + C_e^*/p_i \ [\alpha_i + \textstyle\sum_j \beta_{ij} \ ln(p_{ej}) + \gamma_i \ ln(C_y^*/P_y^*) + \zeta_k Z \,] \quad (16)$$

$$C_e^* = C_e - (\textstyle\sum f_j \, p_{ej}) \quad (17)$$

$$P_e^* = \textstyle\sum_i wki \ ln(p_{ei}) \quad (18)$$

Where $i=1,2$ and f_i, α_i, β_{ij}, γ_i, ζ_k, φ_k, w_{ki}, C_{ye}* and P_e* have the same interpretation at the elementary level.

In order to include the effect of climate into the demand system we assume a translating procedure, which entails to define: $f_i = f_i(\Phi)$. Notice that in the quantity expenditure space, translating has the effect to shift the Engel curve (Bollino et al. 2000).

With theoretical restrictions, there are 11 structural parameters to be estimated in the system of equations (12)-(15) and 11 structural parameters in the system of equations (16)-(18).

Restrictions associated with the estimation results

We have imposed and tested six restrictions that are nested in the general model (R1, R2, R3 R4, R5 and R6). We have also estimated three restricted versions of the GAI demand system, namely using the simple Cobb-Douglas (CD), the Linear Expenditure System (LES) and the original (AI).

The GAI demand system has been estimated in the three different cases taking each separate restriction: the simple Cobb-Douglas (CD), the Linear Expenditure System (LES) and the original (AI).

The restriction R1 imposes zero committed quantities: $fk = 0$ for $k=[y,e]$ and $fh = 0$ for $\forall h \in [k]$ and $k=[y,e]$, in order to test whether committed quantities are significant. This tests the generalization of the GAI over the AI and of the LES over the CD.

The restriction R2 allows to test the GAI functional form versus the LES and the AI versus the CD.

The restriction R3 imposes zero assumptions to the capital stock parameter: $\zeta_k = 0$ for $k=[y,e]$, in order to test whether the effect of the capital stock on the demand system is significant.

The restriction R4 imposes zero restriction to the weather variables, in order to test whether the effect of the weather on the demand system is significant.

The restriction R5 imposes zero cross price effects: $\beta_{ks}=0$ for $k\neq s$ for $k=[y,e]$ in the first stage and $\beta_{hj}=0$ for $h\neq j$ for $\forall h \in [k]$ and $k=[y,e]$ in the second stage, in order to test whether there exists a non-zero relationship of substitutability or complementarity among different goods demands.

The restriction R6 imposes in the second stage that demand is exogenous, with a zero restriction on all price and expenditure structural parameters α_i, β_{hj} and γ_h, in order to test the validity of the multi-stage assumption.

The estimation results and the likelihood ratio values are reported in Figure 4. Estimation of the general form equation systems GAI yields satisfactory results in both stages and in all periods, as shown in the upper part of Panels A and B of Figure 4.

In particular, we notice that the Likelihood Ratio tests on parameter restrictions R1 R2 confirm that GAI is a statistically significant generalization of the original AI model in both stages and in all periods, as indicated by the rejection of the joint zero committed quantity parameter restriction. In addition GAI is superior to LES and CD. In fact, the LR test is minus twice the difference in the reported Log likelihood values and is in the order of magnitude of thousands, against the chi-square critical values at 1%, which are in the order of magnitude of less than hundreds.

The test on the restriction R3 confirms the significance of the capital stock coefficients, again with a LR value decisively higher than the chi-square critical value.

The test on restriction R4 confirms the significance of the weather coefficients, for both the cooling degree days and the heating degree days variables with a LR test value decisively higher than the chi-square critical value. This is a novel empirical result because there are no previous estimations of the effect of this variable on the utility maximizing consumer behavior.

The rejection of the restriction R5, i.e. the exogeneity of the cross price parameters, (the LR test is largely above the critical value) is important. These results combined show that electricity demand is responsive not only to its price but also to prices of other energy goods and other composite goods. This is true both in the first stage at aggregate level of group demand and in the second stage at the elementary level.

The rejection of the joint zero cross price restriction R6 is very important (the LR test is largely above the critical value) because it allows us to reject the hypothesis of price independence in the first stage between composite good and energy and in the second stage among different elementary goods at the 1% confidence level, implying that consumers allocate simultaneously both the group demand and the elementary goods demand.

Panel A First stage estimation – 117 countries – 1978-2012 - no. obs. = 2007

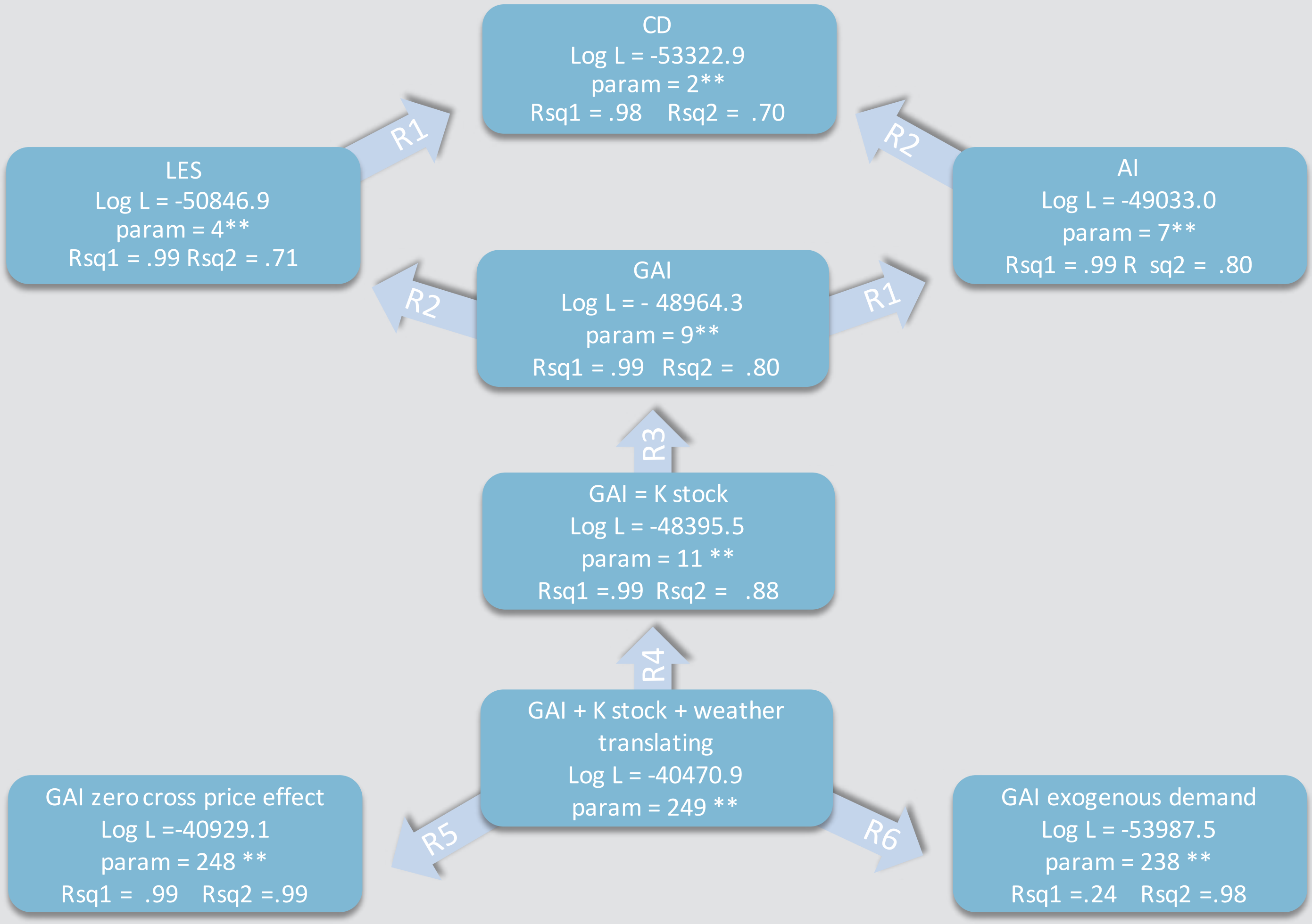


Figure A4a. Estimation results and likelihood values.

Arrows indicate restrictions: R1 R2 R3 R4 R5 R6.

Log L = Log of Likelihood.

param = number of estimated parameters.

** indicates that all structural parameters are significant at 1% level.

Rsq1 = R-square of eq. 1.

Rsq2 = R-square of eq. 2.

Source: KAPSARC analysis.

Panel B Second stage estimation – 46 countries – 1978-2012 - no. obs. = 1350

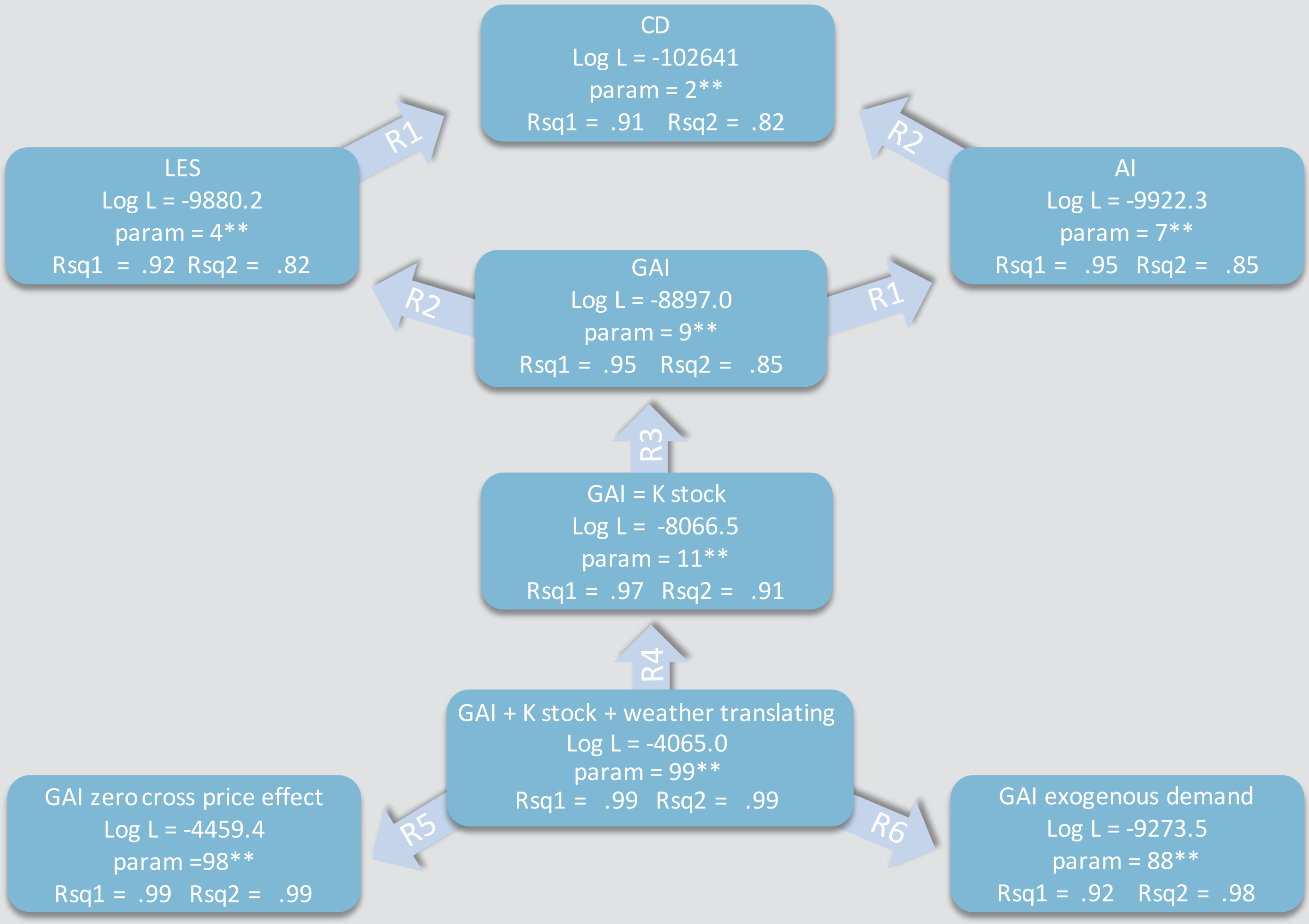


Figure A4b. Estimation results and likelihood values.

Arrows indicate restrictions: R1 R2 R3 R4 R5 R6
Log L = Log of Likelihood
param = number of estimated parameters.
** indicates that all structural parameters are significant at 1% level.
Rsq1 = R-square of eq. 1. Rsq2 = R-square of eq. 2

Source: KAPSARC analysis.

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About the Project

KAPSARC is analyzing the shifting dynamics of the global gas markets. Global gas markets have turned upside down during the past five years: North America has emerged as a large potential future LNG exporter while gas demand growth has been slowing down as natural gas gets squeezed between coal and renewables. While the coming years will witness the fastest LNG export capacity expansion ever seen, many questions are raised on the next generation of LNG supply, the impact of low oil and gas prices on supply and demand patterns and how pricing and contractual structure may be affected by both the arrival of U.S. LNG on global gas markets and the desire of Asian buyers for cheaper gas.

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