Econometric Analysis of Household Coal Demand in Kazakhstan

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Residential sector energy policies are important for addressing key economic, social, and environmental challenges in Kazakhstan. In 2012, the share of households that used coal as a primary source of space heating energy was 70% in rural areas and 32% nation-wide. In addition, between 2002 and 2012 average household annual consumption of coal increased by 44%. Even though coal price was estimated to be subsidized at 60% of full cost, space heating accounted for 35% of an average household's energy budget.

Our study fills in a considerable gap in literature on household coal demand. Using Kazakhstan's household budget survey data from 2002-2012, we estimate a cross section and a dynamic panel data models of coal demand. We find that climatic factors, coal price, and household income are the main drivers of coal demand. Efficiency improvements have a modest impact on coal demand as low coal prices provide little incentives to undertake weatherization. We find that in the absence of relevant policies an average rural household will not be able to switch away from coal. However, we demonstrate that financing rural households' adoption of a clean alternative requires less funds than the current coal subsidy. Finally, we believe that the proposed rural energy policies will stimulate development of Kazakhstan's exceptional renewable energy potential.

HOUSEHOLD COAL DEMAND FUNCTION

We model coal demand of household i in a given period as a function of that period's coal price, income, access to alternative heating systems, observed dwelling characteristics, observed characteristics of the household, the expected length of the heating season and associated outdoor temperature, and other unobserved factors. As a result, the cross-section econometric model of household coal demand is specified as follows:

$$\begin{aligned} log(coal\ quantity) = &\ \beta_0 + \beta_1 log(coal\ price_i) + \beta_2 log(income_i) + \beta_3 alt\_access_i \\ &+ \beta_4 dwelling\_variables_i + \beta_5 household\_variables_i \\ &+ \beta_6 heating\_season\_variable_i + \epsilon_i \end{aligned} \quad (1)$$

Under model specification (1) coefficient estimates represent estimates of elasticity for those explanatory variables that are in the natural logarithm form. Specifically, elasticity of coal demand, Q, with respect to any continuous variable, *X*, is defined as $\%\ \Delta Q/\%\ \Delta X = dlogQ/dlogX = \beta$. Elasticity is a measure of sensitivity of demand to changes in values of the variable X. If X is a dummy variable, its proportionate impact on Q is calculated as ($exp\beta\text{-}1$). In addition, we are interested in analyzing changes of properties of coal demand over time. However, our data (described in the following section) represents annual surveys of different sets of households. As a result, in our dynamic model we cannot use a household as a unit of analysis. Therefore, we use average coal consumption per household in a relevant region to specify the following dynamic panel model of coal demand for region j and time period t as follows:

$$\begin{aligned} \Delta log(coal\ quantity_{jt}) = &\ \Psi_0 + \Psi_1 \Delta log(coal\ price_{jt}) + \Psi_2 \Delta log(income_{jt}) \\ &+ \gamma \Delta log(coal\ quantity_{j,t-1}) + \Psi_{jt} \end{aligned} \quad (2)$$

This model relies on the assumption of capital stock (captured by the lagged dependent variable) as a determinant of the level and the growth rate of demand and the degree of substitution flexibility. Under model specification (2) variables would represent region averages while estimates of Ψ_i and $\Psi_i/(1-\gamma)$ are interpreted as estimated short-run and long-run elasticities, respectively.

THE DATA

Data on household *annual coal expenditures* are collected by the Household Budget Survey (HBS). Like in many national HBSs, household-level data on energy prices and quantities consumed are not part of Kazakhstan HBS. As a result, we use data on average coal prices in region centers.

We use three separate variables to capture efficiency characteristics of a dwelling. First, we use the *post-1990*, a dummy variable for dwellings built in 1990 or later, as a proxy for the original energy efficiency of the dwelling. 1990 was chosen as threshold period to account for the structural changes that

Variable name	Coefficient	Standard error	t-statistic
ln coal price	0.787	0.072	10.990
ln income	0.345	0.020	17.390
alt_access	-0.161	0.057	-2.820
ln area	0.116	0.026	4.380
Apartment	0.019	0.031	0.610
semi-detached	-0.022	0.027	-0.800
post_1990	-0.055	0.028	-2.010
Rental	0.140	0.042	3.330
Pensioners	0.043	0.021	2.060
Children	0.049	0.020	2.430
ln HDD	0.805	0.067	12.020
Constant	-8.069	1.123	-7.180

R^2 = 0.1278; Number of observations = 3209.
Test of endogeneity:
Durbin score chi2 (1)= 70.69 (p-value:0.00);
Wu-Hausman F (1, 3196) = 71.99 p-value (0.00)

Table 1. Characteristics of coal-consuming rural households in 2012

began in Kazakhstan as a result of the breakup of the Soviet Union and transition from central planning to market economy. Next, similar to other studies, we use dummies for *tenant-occupied properties*. The assumption is that such dwellings would be characterized by lower efficiency as tenants often have no capacity and landlords have no incentive to invest in efficiency improvements. Lastly, we consider dummy variables for a *type of dwelling*: an apartment, semi-detached, and detached house. Data on these three variables are available from the HBS.

Furthermore, household coal demand depends on the outdoor temperature and the length of the heating season. Thus, we use heating degree days *(HDDs)* which represent the product of the number of days when average daily temperature is less than 65 degrees Fahrenheit and the absolute value of the difference between 65 degrees Fahrenheit and the actual average daily temperature.

Finally, *household monetary income, dwelling area,* and a dummy variable for *pensioners* are obtained from the HBS. The latter variable is indicative of the time spent at home and thermal comfort levels of household members. To summarize, all data other than coal prices and HDDs are from the HBS and reported at the household level. *Household monetary income, annual coal expenditures,* and *living area* are determined on a per-capita basis. Summary statistics are presented in Table 1.

ESTIMATION PROCEDURE AND RESULTS

Our empirical framework is set up based on Kazakhstan's HBS data which do not have information on household-level coal prices and quantities. Therefore, for the initial stage of our analysis we use annual household expenditures on coal as the dependent variable. Applying cross-section model (1) above to the 2012 household level dataset – with coal expenditures substituted for coal quantities – we obtain parameter estimates obtained by applying Ordinary Least Squares (OLS) estimation procedure (See Table 2). We justify using the OLS procedure by the assumption of the perfectly elastic coal supply curve faced by an individual household.

By dividing household coal expenditures by the coal price we may obtain the imputed household quantity of coal consumed as shown in model (1). In such a case, the only coefficient estimate that differs from the results reported in Table 2 is the one related to the price variable. This specification allows us to compare our findings to those from other studies that use coal quantity as their dependent variable. Specifically, our estimated price and income elasticities of coal demand are -0.50 and 0.47, respectively (See Table 4). The estimate of price elasticity of coal demand is close to the value of -0.38 reported for the residential coal demand in China reported in Zhang and Kotani's (2012) cross-section study. However, the unit value of income elasticity reported by that study is much higher than our estimate of 0.47. Differences in per capita income in Kazakhstan versus China may be the reason of discrepancies in the associated income demand elasticity estimates. In addition, the fact that in China coal is used for both cooking and heating while in Kazakhstan it is used primarily for heating purposes may be another reason for differences in estimated demand elasticities.

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R^2 = 0.1278; Number of observations = 3209.
Test of endogeneity:
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Table 2. Coal Expenditures Model Estimation Results (2012 Cross-Section Household Level Model)

Next, we estimate long-run price and income elasticities according to specification (2). As the specification of the residential demand equation introduces correlation between the errors and the lagged first-differenced endogenous variable, we use the Arellano-Bond System GMM approach (Arellano and

Bond, 1991; Blundell and Bond, 1998). Under this approach we include second through eleventh lags of all variables as GMM-style instruments. Here variables represent averages across households in a given region. Estimation results are obtained for the period of 2001-2012 and 12 regions (See Table 3). Results indicate that short-run income elasticity of coal demand estimated at the region level is 0.34 and associated short-run price elasticity is -0.65. Corresponding long-run income and price elasticities are 0.60 and -1.15, respectively.

Variable name	Coefficient	Robust Standard error	z-statistics
Δln coal price	-0.653	0.276	-2.37
Δln income	0.340	0.198	1.72
Δln living area	1.128	1.362	0.83
ΔLagged endogenous variable	0.430	0.128	3.37
Constant	-1.527	3.276	-0.47

Wald χ^2-statistic = 266.04; Number of observations = 132.
Test of overidentifying restrictions:
Hansen's J-statistic: 12.76 p-value (0.174)
Test of stationarity of dependent variable:
Levin–Lin–Chu panel unit root (t-statistic): -2.226 p-value (0.013)
Test for autocorrelation:
Arellano–Bond test of AR(1) in residuals (z-statistic): -3.06 p-value (0.002)
Arellano–Bond test of AR(2) in residuals (z-statistic): -1.84 p-value (0.065)

Table 3. Dynamic Panel Data Coal Quantity Model Results: Arellano–Bond System GMM

POLICY IMPLICATIONS AND CONCLUSIONS

Model	Price elasticity	Income elasticity
Dynamic panel data model	Short-run: -0. 65 Long-run: -1.15	Short-run: 0.34 Long-run: 0.60
Cross-section model	-0.21	0.35
Cross-section model (Zhang & Kotani, 2012)	-0.38	1.00

Table 4. Demand elasticity estimates

Our study provides the following implications for energy policies aimed at reducing coal use by rural households:

1. *Raising of coal prices will have a limited impact on household coal.* If we assume that real income grows at 2% and real coal prices grow at 9.5% per year then coal demand would decrease by only 4.7-6.2% in the short run. In that case the current coal subsidization rate of 60% (IEA, 2013) will be eliminated over ten years. This limited ability of households to adjust to rising coal prices may be related to the fact that during the heating season the indoor temperature in rural areas is low and cannot be further decreased to allow a household to economize on coal expenditures. However, the primary reason for the low price elasticity of household coal demand is lack of substitute fuels. Of all rural households for whom coal represents the primary source of space heating energy only 3% have access to central heat or network natural gas. Wood burning is not a viable alternative for most households due to the scarcity of fuel wood: forest area as share of all land area in Kazakhstan represents only 1.2%.
2. *Government plans to expand the natural gas network will be of limited consequence for rural coal-using households*. Currently, alternatives in the form of network natural gas and central heat are restricted to urban areas and some rural locations along natural gas pipelines. The government plans to achieve increasing the share of population with access to network gas from 42% to 56% by 2030. This program would benefit some of the current coal users who represent 32% of population. However, provision of access to gas in many rural areas would be extremely costly due to large distances between communities and low density of population in Kazakhstan.
3. *Electricity based space heating systems may represent a viable alternative to coal in rural areas*. There may exist several attractive technologies such as geo-thermal, direct solar, or bio-gas based heating systems suitable for application in Kazakhstan. Of all possible technologies we focus on electricity-based systems because such technologies are actively penetrating the market for heating equipment in Kazakhstan. Electric boilers are becoming popular due to the possibility of using them overnight when electricity tariffs are low. (For example, in Kostanai region in Northern Kazakhstan, 2015 tariffs were 2.6 and 11.8 US cents/kWh for night time and day time, respectively). The price of such boilers varies between $200 and $1000. Such electric boilers have 98% efficiency and require 1 kW of electricity to heat 10 m^2 of an energy efficient house for one hour, assuming that outdoor temperature is -20ºC and indoor temperature is +20ºC. As a result, the cost of electricity required to heat an energy efficient house of an average size of 70 m^2 in Northern Kazakhstan would be $45 per month if overnight tariff is used. The boiler would be on for only 8 hours during the night and the rest

of the time hot water would be circulated through the radiator system requiring minimum energy. This estimate may be compared to the cost of heating an average (low efficiency) house in Northern Kazakhstan using a combination of coal and wood which accounts for $57 per month.

4. *Conversion to electric heat is not affordable for an average rural household*. The cost of electric heating system should include expenses on purchasing the boiler, a thermostat, radiators and pipes, heat collector, and electronic meters. In addition, weatherizing the house needs to be financed. Howie and Pak (2015) estimated that the cost of purchasing and installing electric boiler heating system in Kazakhstan in 2014 was $2700. In addition, the authors estimated that the cost of weatherizing a 70 m^2 house built prior to 2000 at $7700. (Note that 94% of houses of rural coal-using households were built prior to 2000.) This means that to finance conversion to electric heat a total of $10,400 would be required compared to $9,500 which represented average rural household income in 2014.
5. *Phasing out coal price subsidies generates sufficient funds to support coal-to-electricity conversion by rural households.* Let us estimate the costs of subsiding conversion to electric heating system by rural coal users who represent around 1.586 million households. Assuming that the 50% of the weatherization cost is financed using a 15-year government bond at a 7.5% annual interest rate, the annuity equivalent payments would be $0.7 billion. Let us compare their size to the amount of annual coal subsidy in Kazakhstan. In 2011 coal price subsidy in Kazakhstan represented $5.3 billion on a post-tax basis (IMF, 2013). Since households account for roughly 19% of all coal consumed in Kazakhstan (Kazakhstan Government, 2008), the current annual coal post-tax subsidy directly attributed to household consumption is $1 billion. In other words, ignoring its inflationary effect phasing out of coal subsidies would generate sufficient funds to finance transition of rural households to electric heat. Reduced health hazard, lower pollution levels, increased thermal comfort, and released labor input necessary to serve the coal furnace represent co-benefits of avoided public spending from phasing out coal price subsidies.
6. *Developing Kazakhstan's renewable electricity potential and declining export demand for its coal will make coal-to-electricity conversion more feasible.* Phasing out coal subsidies will lead to higher electricity prices as 75% of power in Kazakhstan is generated from coal. However, an expected decline of coal exports from Kazakhstan may dampen the upward pressure on electricity prices from reducing coal subsidy. Currently, Kazakhstan exports 30% of its coal production to Russia accounting for 20% of Russian coal-firing generation needs. However, many of the Russian coal-fired plants using coal from Kazakhstan are likely to be decommissioned within the next 10 years. More importantly, Kazakhstan has exceptionally high potential of generating electricity from renewable sources. More than 50% of Kazakhstan's territory has a wind speed of 4-5 m/s at 30 meters height. Industrial scale wind farms are being developed in locations with wind speed of 8-10 m/s at 30 meters height. Average annual insolation in Kazakhstan is 1,300-1,800 kW/m^2 and average annual insolation duration is 2,200-3,000 hours. Currently, wind, solar energy, and small hydro plants account for only 0.6% of 19TW of installed capacity in Kazakhstan. However, technical potential for installed renewable electricity capacity is 354TW for wind energy and 3,760TW for solar PV (UNDP, 2014). As a result, promotion of small-scale heating technologies based on on-site heat or electricity generation should be considered. Our study shows that there is a large hidden demand for these sources of renewable energy associated with space heating needs of households in rural areas.

To summarize, our study represents the first attempt to identify and quantify determinants of household coal expenditures and coal demand in Kazakhstan. Our results indicate that, on the one hand, continued economic growth will be associated with increasing rates of coal use. On the other hand, raising coal prices will achieve moderate reduction of coal use in rural areas. As a result, addressing coal use in rural areas requires a concerted policy effort aimed at phasing out coal subsidies, designing programs supporting coal-to-electricity conversion, and promoting renewable energy technologies in rural areas.

(See references on page 39)