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Rebound Effect of Residential Space Heating: The Case of Ankara

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The direct rebound effect for space heating targeting households in Ankara, Turkey, is calculated by using primary and socio-economic indicators related data for energy efficiency applications in buildings. The demographic, dwelling characteristics, and behavioral factors that affect gas consumption are included in the analyses and are found to be crucial to assuring the successful implementation of energy efficiency technology in space heating.

I. Introduction

Energy efficiency and technology innovations are becoming more important in global energy policy discussions due to the need to conserve energy and reduce greenhouse gas emissions. Technological developments contribute to more efficient energy services and lower costs. The lower costs lead people to either consume more efficient energy services because of its substitution effect or to consume other energy services with the money saved due to its income effect, a phenomena called the rebound effect (RE). Specifically, the substitution effect of the reduced energy prices is direct RE (DRE), while the income effect is indirect RE. Due to the substantial share of domestic heating in energy consumption, understanding the RE after energy-efficient building technology implementations has received much interest (see e.g., study1; study2). This article calculates the DRE for home heating in Ankara, Turkey, due to improved building insulation.

The RE literature, initially sourced from Jevons book "The Coal Question: can Britain survive?" (Jevons, 1865), mostly focused on energy efficiency in buildings, industry, and transportation recently. The DRE of household heating improvements is one of the most widely studied topics (Sorrell et al., 2009). Moreover, recent attention has been directed from technological improvements to the socio-economic factors influencing the DRE. This line of research has reported that the income level of households has a significant impact on the RE size (Guertin et al., 2003; Hache et al., 2017). Peters and McWhinnie (2017), Milne and Boardman (2000), and Madlener and Hauertmann (2011) report even stronger RE for low-income groups. Most of the studies have examined RE by utilizing data from developed countries (i.e., Lu et al., 2017). Freire-González (2011) claims that RE is higher in developing countries. Therefore, analyzing RE in a developing country by incorporating socio-economic factors will be an important contribution to the literature and global policy agenda.

According to the Turkish Energy Efficiency Strategy Paper for 2012-2023, increasing buildings' energy efficiency is a priority in Turkish energy policies. The government aims to reduce building energy demand by integrating renewable energy technologies. This goal depends on reducing building energy consumption, which relates to technology and consumer behavior. Since energy efficiency may cause economic agents to change their behavior, calculating the magnitude of RE in houses owing to building insulation can help policymakers analyze energy strategies.

The contribution of this paper is threefold. First, the DRE for residential households is calculated using primary data. Second, demographic factors, dwelling characteristics, and behavioral characteristics related to gas consumption are identified using household data. Third, the relations between income groups and RE are explored.

The rest of the paper is outlined as follows: Section II explains the data and methods, Section III reports the results, and Section IV concludes.

II. Data and Methods

The data is obtained from a survey, energy certificates of buildings, and gas consumption invoices. The questionnaire is based on literature and expert interviews. The questionnaire covers economic, demographic, and household behavior. The expert interviews offer information about RE in buildings. The survey is conducted in Ankara for 317 households (0.02% of the total in 2018) selected from the seven most densely populated districts out of 25

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(Ankara Kalkınma Ajansı, 2017). Within the districts, renovated homes to improve insulation data is obtained from IZODER (Heat Water Noise and Fire Insulators Association), which provides the addresses and contact details of 771 renovated buildings between May 2011 and April 2017. Assuming each building has ten units, the population size is approximately 7,710 inhabitants. The sample size is determined as 308 for a 0.05 alpha value according to the *sample size table* in Yazıcıoğlu and Erdoğan (2004). However, to avoid missing data problems, 317 households are surveyed for the study. Before running the survey, a pilot study was conducted.

The energy certificates are displayed in every building and were obtained during the survey. The certificates are used as a proxy for the energy efficiency of the dwellings, which consists of total energy use, the energy intensity of various energy services, CO2 emissions, and building energy labels.

Başkent Doğalgaz Dağıtım A.Ş., the gas distribution company, provides gas consumption data. Our calculations are based on 2018 income and gas consumption figures to match the survey. Gas consumption data includes heating and residential hot water. Therefore, to subtract gas consumption for heating, we used the share of gas for heating indicated in the energy certificate for each building.

Literature provides two elasticity approaches to calculate DRE: elasticity of energy consumption for energy efficiency and energy prices. Following Aydin et al. (2017), we employ the former elasticity. Energy efficiency is proxied by energy intensity, which is the amount of heat required to maintain a certain level of thermal comfort (Grossmann et al., 2016). This is also called heating efficiency. Thus, we define RE as follows:

$$\tau_G = \partial \ln(H)/\partial \ln(\mu_H). \tag{1}$$

Measured by the temperature level, percentage of the heated space, etc., H is the residential energy consumption on heating by households. μ_H is the heating efficiency, which is measured as the ratio of the amount of reference heating required in a year (say, H_r) to the amount of gas that is necessary to reach that heating level (say, G*). The amount of reference heating has a fixed value and is acquired from the energy certificates.

We assume that the residential energy consumption on heating and the households' actual gas consumption (G^a) are proportional. Thus, H can be written as follows:

$$H = H_r\,(G^a/G^*) \tag{2}$$

As a result, RE can be reformulated as follows:

$$\tau_G = \partial \ln\left[H_r\left(\frac{G^a}{G^*}\right)\right]/\partial \ln\,[H_r/G^*]. \tag{3}$$

Since H_r is a scalar, we also have the following equation as RE:

$$\tau_G = 1 - \partial \ln(G^a)/\partial \ln(G^*) \tag{4}$$

We use the standard econometric model to estimate the energy efficiency elasticity of residential heating, as follows:

$$\ln(G_i^a) = \beta_0 + \beta_1 \ln(G_i^p) + \sum_{j=2}^{j} \beta_j Z_{ji} + \alpha_i + \varepsilon_i \tag{5}$$

where the index i denotes households and G^p is the predicted gas consumption. We use G^p instead of G^*, since G^* is a theoretical value. Z_{ji} is the vector of the control variables that can be observed through surveys. α_i represents the error term specific to household i. ε_i is the independent and normally distributed error term.

We use the estimated coefficient β_1 to calculate RE as follows:

$$\tau_G = 1 - \beta_1. \tag{6}$$

We employ cross-sectional techniques to estimate the empirical model in Equation (5). The dependent variable of this model is the amount of gas (m^3) that households consume. The predicted gas consumption is proxied by the heating intensity (*kWh/m^2*-year) and obtained from energy certificates. Control variables include 50 demographic, dwelling characteristics, and behavioral factors. We firstly utilize the related literature to determine them. After observing them via surveys, we apply the stepwise and backward methods to select the significant variables that need to be included in the final model. Furthermore, we explore whether households in different income groups show different RE sizes.

III. Empirical Results

The estimated parameters for the factors determining gas consumption in retrofitted households, the RE size, and the RE's sensitivity to the income level are calculated and reported in Tables 1 and 2.

For factor determination, we apply backward and stepwise ordinary least squares (OLS) approaches to Equation (5). We determine the models with the most appropriate control variables out of the 50 variables obtained through surveys. Columns (1) and (3) of Table 1 report the estimation results of the final models with the *remaining* significant coefficients. Table 1 also reveals the demographic, dwelling, and behavioral characteristics that affect households' gas consumption. The estimated models indicate almost similar variables for the two models, with the exceptions that the *OLS-backward* method yields a *dwelling's position to be on the top* and *having neighbors that heat from up and down*. In contrast, the *OLS-stepwise* method chooses *having a neighbor that heats from down*. Both estimates suggest that the rise in household size, number of heaters, and number of cars owned increases gas consumption. When families replace boilers after insulation and males decide on heating, gas consumption is relatively high. The number of floors, apartment on top, using outside temperature for heating, and hermetic boiler negatively affect gas usage. The backward method shows having upstairs and downstairs neighbors reduces consumption, whereas the stepwise method suggests having only downstairs neighbors increases consumption.

Engineering predictions might contain a measurement error, which leads to a downward bias in the estimated RE (Aydin et al., 2017). This error is taken into account by including a multiplicative error component in the predicted theoretical gas use. To circumvent the bias problem, we apply the instrumental variable (IV) method and add *dwelling age* as an IV for energy efficiency, following Aydin et al. (2017). Dwelling age is a good candidate for IV since it is correlated with the predicted theoretical gas use but uncorrelated with the measurement error (Aydin et al., 2017). Besides, dwelling age affects gas consumption via only energy efficiency (Volland, 2016).

Therefore, we employ a two-stage least squares (2SLS) estimation approach to each model using dwelling age as IV. The results of the 2SLS estimations are also reported in Table 1. Even though the estimates remain similar in signs, the significant coefficients get slightly larger except for the coefficients of the number of cars owned and using a hermetic boiler.

The RE is calculated as approximately 70% (i.e., 1 – 0.293) for both the *OLS-backward* and *OLS-stepwise* models. These values indicate a large RE size. However, RE is about 48% (i.e., 1 – 0.518) for both the 2SLS models, which suggests that half of the expected energy efficiency is not accomplished due to RE. Thus, the use of IV eliminates the potential overestimation problem.

Finally, we investigate whether the size of RE depends on the income levels of households as suggested in the literature (Guertin et al., 2003; Hache et al., 2017). The RE is expected to be higher in lower income groups because energy services already make up a larger share of their budgets, and the increased real income will be spent on essential goods (i.e., food and energy services) more than in higher income groups. The OLS estimates RE for each income group based on TÜİK (2017) data.[1] Low- and medium-income households have similar RE, while high-income households have a lower RE (59%) (Table 2). The results are aligned with Peters and McWhinnie (2017) and Madlener and Hauertmann (2011). When households are clustered by income, the important factors of gas consumption change. Income categories also affect them.

IV. Conclusions

Our analyses show that RE is about 50% in Ankara households with insulation. This study is the first to calculate DRE for households' space heating using primary data for Turkey. The RE is higher in low- and medium-income groups, suggesting the development of different carbon and energy tax policies for each income group. Household size and income positively affect gas consumption. The number of floors and apartment floor numbers tend to negatively affect gas usage, whereas the number of bedrooms, number of heaters, boiler change after insulation, and average temperature preference positively affect it. The outside temperature and temperature adjustment due to economic concerns reduce gas consumption, whereas the number of cars (a sign of high-income households) increases it.

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1 http://www.tuik.gov.tr/UstMenu.do?metod=temelist

Table 1. Pooled OLS and Instrumental Variable Estimations

		(1)	(2)	(3)	(4)
Characteristics	Independent variables	OLS Backwards	2SLS (1) Dwelling Age	OLS Stepwise	2SLS (3) Dwelling Age
	Heating intensity (logarithm)	0.293***	0.518**	0.297***	0.514**
		(8.123)	(2.168)	(8.284)	(2.255)
DE	Household size (logarithm)	0.310***	0.337***	0.309***	0.332***
		(3.953)	(3.795)	(3.941)	(3.811)
D	Total No. of Floor	-0.063***	-0.077***	-0.064***	-0.077***
		(-5.731)	(-3.979)	(-5.864)	(-4.282)
D	Position: top	-0.157*	-0.151		
		-1.719	(-1.537)		
D	Number of heater	0.055**	0.064***	0.053**	0.060**
		(2.36)	(2.396)	(2.335)	(2.361)
D	Change boiler after insulation	0.298*** (3.334)	0.313*** (3.219)	0.303*** (3.374)	0.316*** (3.262)
D	Boiler type: Hermetic	-0.213***	-0.171*	-0.215***	-0.173*
		(-2.714)	(-1.799)	(-2.726)	(-1.825)
D	Neighbor heating: both	-0.191**	-0.109		
		(-2.502)	(0.916)		
D	Neighbor heating: below			0.163**	0.099
				(2.064)	(0.917)
B	Household member taking heating decision: male	0.311*** (3.581)	0.325*** (3.445)	0.301*** (3.462)	0.316*** (3.357)
B	Reasons effecting heating consideration: Outside Temperature	-0.247***	-0.267***	-0.238***	-0.260***
		(-3.82)	(-3.683)	(-3.667)	(-3.562)
B	Cars owned	0.203***	0.201***	0.214***	0.208***
		(3.525)	(3.248)	(3.691)	(3.334)
	(Constant)	4.914***	3.924***	4.738***	3.857***
		(18.236)	(3.628)	(18.028)	(4.039)
	R^2	0.464	0.354	0.459	0.346
	Adjusted R^2	0.441	0.326	0.438	0.321
	Rebound Effect	0.707	0.482	0.703	0.486

Notes: *** 1%, **5%, *10%. The figures in parentheses are *t*-values. DE stands for demographics, D for dwelling, and B for behavioral

Table 2. Rebound Effects in Income Groups

	(1) *Low-Income*	*(2)* *Medium-Income*	*(3)* *High-Income*
Heating intensity (logarithm)	0.271***	0.298***	0.388***
	(6.313)	(6.499)	(3.627)
Household size (logarithm)	0.291***	0.481***	0.436**
	(3.356)	(3.746)	(2.656)
Neighbor heating: both	-0.23***		
	(-2.816)		
Total Number of Floors		-0.067***	-0.067***
		(-4.411)	(-3.010)
Reason affecting heating consideration: Temperature		-0.739*** (-5.825)	
Reason affecting heating consideration: Children		-0.503*** (-2.95)	
Reasons affecting heating consideration: Economic		-0.626*** (-4.149)	
Number of heaters			0.153*** (3.113)
Decision: male		0.327**	
		(2.499)	
Months passed after the insulation		-0.001** (-2.056)	
Position: Basement		0.571***	
		(2.714)	
Boiler: Hermetic		-0.365***	
		(-2.909)	
Number of cars owned		0.222**	
		(2.372)	
(Constant)	5.404***	5,517***	3,651***
	(25.715)	(19.553)	(5.873)
R^2	0.623	0.522	0.353
Adjusted R^2	0.591	0.480	0.319
Rebound Effect	73%	70%	59%

Notes: *** 1%, **5%, *10%. The figures in parentheses are *t*-values.

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