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Energy Efficiency Barriers in Commercial and Industrial Firms in Ukraine: An Empirical Analysis[*]

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Abstract

Improvement in energy efficiency is one of the main options to reduce energy demand and greenhouse gas emissions. However, large-scale deployment of energy-efficient technologies is constrained by several factors. Employing a survey of 509 industrial and commercial firms throughout Ukraine and a generalized ordered logit model, we quantified the economic, behavioral, and institutional barriers that may impede the deployment of energy-efficient technologies. Our analysis shows that behavioral barriers resulted from lack of information, knowledge, and awareness are major impediments to the adoption of energy-efficient technologies in Ukraine, and that financial barriers may further impede investments in these technologies especially for small firms. This suggests that carefully targeted information provisions and energy audits will enhance Ukrainian firms' investments in energy-efficient technologies to save energy consumption, improve productivity, and reduce carbon emissions from the productive sectors.

***JEL Classification**:* O1, O3, Q40

***Keywords**:* Energy-efficiency, barriers to energy efficiency, discrete choice models, generalized ordered logit model, Ukraine.

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1. Introduction

The adoption of energy-efficient technologies has been touted as a major policy option to save energy consumption and reduce greenhouse gas (GHG) emissions. The International Energy Agency estimates that energy-efficient technologies offer the highest potential in the total GHG mitigation required to limit global temperature rise by 2050 to 2°C above pre-industrial levels (International Energy Agency, 2012). Many of the studies that develop marginal abatement cost curves for GHG mitigation demonstrate that energy-efficient technologies entail negative costs (i.e., value of energy savings exceeds investment costs even if GHG mitigation benefits are not accounted for) and therefore these options are interpreted as “low-hanging fruit” for climate mitigation (Asian Development Bank, 1998; McKinsey & Company, 2009; Energy Sector Management Assistance Program, 2012). Energy-efficient technologies save firm’s expenditures on energy resulting in their overall cost efficiency.

In practice, however, the scale of implementation of such seemingly win-win options are small in relation to their apparent economic potential. The rationale for this disparity is that implementation of these options is constrained by economic and institutional barriers (Jaffe & Stavins, 1994; Howarth & Sanstad, 1995; Sorrell et al., 2004; Mundaca et al., 2013). Moreover, the estimated benefits of deployment of energy efficient technologies may not be realized in practice. This is because the economics of energy-efficient technologies is normally evaluated using engineering benefit-cost analysis (e.g., Goldstein et al., 1990; Blumstein & Stoft, 1995; Brown et al., 1998; McKinsey & Company, 2009; Gillingham & Sweeney, 2012), which usually omits variables such as opportunity costs of investment and also the transaction costs of the deployment (Allcott & Greenstone, 2014). If the transaction costs imposed by the economic and institutional barriers are accounted for, the net benefits that can be achieved from energy-efficient technologies would be smaller as compared to the opportunity costs of the investment thereby causing firms to lose interest in adopting them (Anderson & Newell, 2004).

The gap between the level of energy efficiency actually realized and that achieved in theory via the implementation of cost-effective energy-efficient technologies is called the “energy efficiency gap” (Blumstein et al., 1980; DeCanio, 1993; Jaffe & Stavins, 1994; Sanstad & Howarth, 1994; Sorrell et al., 2004; Schleich, 2009). In this paper, we revisit this gap while employing survey data collected in 2012 from 509 Ukraine firms. We use the data to empirically examine barriers to the adoption of energy-efficient technologies in Ukraine for both commercial and industrial firms. The empirical analysis employs a generalized ordered logit model (GOL model; Williams, 2006). The selection of the model is based on the fact that GOL models are less restrictive than ordered logit models, whose assumptions are often violated, but are more parsimonious than the multinomial logit models that ignore the ordering of categories.

The empirical analysis is carried out for Ukraine, a small developing Eastern European country, located between Russia and Europe. Its geographic position led it to become transit country of natural gas imported from Russia to Europe (Correlje, 2006; Goldthau, 2008; Soderberghn, 2010). Although historically Russia has supplied Ukraine with natural gas and petroleum at prices much lower than market prices (Dimitrova, 2009), recently Russia has begun pushing for higher prices, resulting in several disputes. The culmination of these disputes came when exports to Ukraine of 90 million cubic meters of natural gas per day were halted on January 1, 2009. Increases in energy prices may result in long-run effects that yield significant changes to the economy's production structure (Schubert & Turnovsky, 2009).

The aging infrastructure and the inefficiencies have led Ukraine to call for increased penetration of clean energy and improved efficiency in utilizing energy. The government has enacted several policies to promote the adoption of clean and energy-efficient technologies (Trypolska, 2012). Adoption of alternative energy technologies and the introduction of energy-efficient technologies can address Ukraine's structural problems, and energy-efficient technologies reduce energy costs and generate economic growth (Gillingham et al., 2014).[2]

However, are current investments in energy-efficient technologies in Ukraine optimal? Do barriers to the adoption of the energy efficient technologies lead to underinvestment? A number of studies attempted, through empirical analysis, to understand the energy efficiency barriers in different countries, sectors, and energy end uses (see, e.g., Rohdin & Thollander, 2006; Sardianou, 2008; Schleich, 2009). The literature suggests that financial barriers such as high upfront costs, lack of information, and priority setting of upper management impede the

[2] Although we still do not understand the magnitude of the rebound effect, current literature offers little support to the Jevons hypothesis whereby the introduction of energy efficiency results in a net increase of energy use (Gillingham et al., 2014).

adoption of energy-efficient technologies. However, to our knowledge, this literature focuses mostly on Organization for Economic Cooperation and Development (OECD) countries, and an in-depth analysis has not been performed to better understand barriers to improvements in energy efficiency among industrial and commercial firms in small developing economies. Our study aims to contribute to filling this research gap. Moreover, the importance of such an analysis has increased tremendously with the current political situation in Ukraine, as energy security has become a key concern.

Our analysis shows that financial and economic barriers (e.g., high upfront costs of energy-efficient devices and processes, high costs of financing due mainly to higher risks perceived by financial institutions in new and emerging technologies) may hamper firms' investments in energy-efficient technologies especially for small firms (measured via revenues). It also shows that, contrary to our intuition, firms do not perceive government regulations and internal corporate bureaucracy as barriers to the adoption of energy-efficient technologies. However, the analysis does suggest that behavioral constraints such as lack of knowledge are major barriers that hamper adoption of energy-efficient technologies and lead to underinvestment in such technologies. Furthermore, we found that the commercial sector, which includes the public sector, is less likely to invest in energy-efficient technologies in the absence of policy interventions, but that mandatory energy audits have a larger effect on the commercial sector.

We organized the paper as follows: Section 2 discusses firms' investment decisions regarding energy-efficient technologies and possible barriers that hinder the adoption of such technology. Section 3 presents the cross-sectional survey data and the empirical analysis, followed by concluding remarks in Section 4

2. The firm investment decision model

We assume a profit-maximizing firm that contemplates whether to invest in energy-efficient technologies. This firm faces two alternative technologies: an energy-*inefficient* technology (henceforth, denoted with subscript 0) and an energy-*efficient* technology (henceforth, denoted with subscript 1). For simplicity, we assume the production function is of fixed proportions and let E denote the fixed-proportion energy-output coefficient; that is, *E* energy units are used to produce one unit of output Q. Also, let p_Q denote output price and let p_E denote energy price. In addition, we assume a risk adjustment discount rate of i.

When modeling the firm's investment decisions, we assumed the firm first decides whether to invest in the energy-efficient technology and then, given its choice, the firm produces and generates profits. That is, we assumed two periods: In period 1, the firm decides whether to invest $I>0$ in the energy-efficient technology, while in period 2, the firm consumes energy and incurs the operating costs of using the energy. The model can be made more complex to include other inputs (e.g., labor), other production functions, and uncertainty, as the literature on the adoption of new technologies suggests (e.g., Sunding & Zilberman, 2001). However, for our purposes, this basic stylized model suffices.

The model contains several economic factors affecting the firm's decision whether to adopt the energy-efficient technology. We assume that an investment of I lowers the firm's energy intensity from E_0 to E_1. In addition, we assume that adoption of the energy-efficient technology encompasses hidden or transaction costs $H>0$ that are unobserved by the econometrician. Other sources of economic costs include the opportunity cost of capital that affects the risk-adjusted discount rate, which can be affected by imperfect credit markets that prevent firms from accessing the capital needed to upgrade a plant and adopt energy-efficient technologies. We denote these types of barriers as *economic barriers*. These economic costs suggest that firms may elect not to invest in energy-efficient technologies because the cost of implementing such technologies is greater than the benefits to the firm.

Economic barriers may limit firms' investment in energy-efficient technologies. Although the investment may be optimal from the firm's point of view, these investments may be socially suboptimal because the calculation leading to firms' investment decisions do not include market distortions caused by environmental externalities (e.g., pollution generated from energy consumption). Thus, market failure results in underinvestment in energy-efficient technologies. On the other hand, imperfect capital markets suggest that firms face capital constraints that reduce the amount invested in energy-efficient technologies. Then, if imperfect credit markets are of concern, development of informal credit markets (Deb & Suri, 2013) and introduction of state-owned development banks (David, 1984; Pulley, 1989) should be contemplated as mechanisms that alleviate the financial constraint. These barriers can be reduced via the introduction of better governance and best practices.

We let *institutional barriers* denote a second group of barriers that may impede the adoption of energy-efficient technologies. The literature suggests that regulation can become a barrier to the adoption of new technologies (Djankov et al., 2002; Graff et al., 2009).[3] Regulation may impose a cost (e.g., licensing, permits), as well as delays to the implementation of the new technology, which may negatively affect firms' incentives to invest in energy-efficient technologies. Formally, we focus on the cost and assume government regulation is costly and results in an additional upfront cost of $\rho > 0$ to the firm.

The literature, however, identifies another important class of barrier that leads to investment inefficiencies resulting in the energy efficiency gap (Alcott & Greenstone, 2012), namely, *behavioral and information barriers*. The firm may not be aware of or informed about the monetary benefits of using energy-efficient technologies. The firm may also not be attentive to its own energy costs. These barriers are the outcome of bounded rationality, perceived credibility and trust, and information. We assume these barriers cause the firm to undervalue the benefits of energy-efficient technologies. Formally, we capture underinvestment in energy-efficient technologies by the parameter $\theta \in (0,1)$, whereby the larger the θ, the larger the energy efficiency gap. Lack of information, awareness, and experience results in a larger θ and in firms undervaluing the benefits of energy-efficient technology.

However, even if the firm is informed and aware of the benefits of the technology, it still may elect not to invest because, for example, the firm may be renting its facility and not paying the electricity bill (i.e., *split incentives*). That is, the firm pays less than p_e for a unit of energy. Clearly, if the company does not pay for energy then it will not invest (recall that the upfront cost is strictly positive). However, even if the firm only pays part of the energy cost, its incentives to invest in energy-efficient technologies are lower than socially optimal. Technically, we assume the firm pays only a share $\zeta \leq 1$ of the energy costs. These split incentives then result in the

[3] Regulation may also facilitate the adoption of new technologies. However, this will not contribute to an energy efficiency gap and thus is not included in the stylized model.

energy efficiency gap and in underinvestment in the technology. Therefore, a profit-maximizing firm invests in the energy-efficient technology if

$$(1-\theta)(E_0-E_1)\zeta p_e Q/(1+i) > I + H + \rho \tag{1}$$

3. The empirical analysis

Policy and mechanisms that foster adoption of energy-efficient technologies depend on the specific barriers that hamper the investments in these technologies. Thus, a better understanding of the importance of the various barriers to adoption of the technology is needed. Using the intuition developed above, a survey is developed and used to assess the importance of the aforementioned barriers (i.e., economic and financial, behavioral and information, and institutional barriers). Building on Rohdin and Thollander (2006) and Sorrell et al. (2004) the survey questions were developed (see Table 1 of Appendix A, as well as Fedets et al., 2013).

3.1 The cross-sectional survey

The survey conducted employed a sample of 509 commercial and industrial firms throughout Ukraine and was implemented through face-to-face and mail interviews with representatives of the chosen firms. To map the sample back to an unbiased representation of the survey population, we weighted the survey data using the prevalence of different firms in the overall economy.

The firms were chosen using a two-stage quota sample (Sorrell et al., 2004), accounting for industrial and commercial energy-intensive firms in all regions of Ukraine. The sample included 61.9% industrial firms (315 of 509) and 38.1% commercial firms (194 of 509). With respect to the industrial sector, a focus was on big firms since they are more likely to be energy intensive. Therefore, small firms (those with fewer than 50 employees) amounted to no more than 10% of all industrial firms, while big firms (with more than 500 employees) comprised no less than 20% of all industrial firms. The quota of small commercial firms (up to 50 employees) was set at no more than one third of the sub-sample. Also, in the commercial sector, firms with a venue area of more than 150 m^2 were selected for the survey because they are likely more energy intensive than those with smaller venues.

The industrial sector includes firms that operate in mining, processing, and other industrial sectors, as well as services supplied to those sectors, while the commercial sector includes firms that provide education, health care, and other services and those of construction and trade.

An important step in the analysis is evaluating the reliability and validity of the survey data. To this end, various experts on the Ukraine economy and in survey design evaluated and assessed the survey, which was revised accordingly. In addition, statistical tools were used to evaluate internal consistency and unidimensionality (Tavakol and Dennick, 2011). Preliminary analysis suggests inconsistency in variables that measure firms' perception of the cost component of energy efficient technologies. Therefore, we do not employ these variables in the statistical analysis. The internal consistency of the items (questions) that were employed in the analysis and used to describe a single concept or construct (e.g., barrier), yielded Cronbach's α of 0.78 or higher thus suggesting good internal consistency (Tavakol and Dennick (2011) and references therein).[4] That is, the expected values of half of the sample (after discarding missing observations) resulted in a similar outcome to that of the remaining half. Put differently, the proportion of the observed variance that represents true variance is at least 74%. The use of Principle Component Analysis offers further support for homogeneity or unidimensionality, where each set of items (questions) measure a single latent factor (see section 3.2 and Appendix B).

The data collected via the survey are used to quantify firms' perceived barriers to the adoption of energy-efficient technologies. In the following paragraphs, we first describe the variables used in the analysis and then discuss the model's specifications.

3.2 The dependent variable and its regressors

The ordinal dependent variable is the amount a firm has invested in energy-efficient technologies in the past five years. This variable is coded as follows:

- 0 if the firm did not invest in energy-efficient technologies (93 firms)

[4] Regulation may also facilitate the adoption of new technologies. But this will not contribute to an energy efficiency gap and thus is n

- 1 if the firm made strictly positive investments of less than US$250,000 (232 firms)
- 2 if the firm invested more than US$250,000 (64 firms)

Because the way questions were structured, we could not normalize investment to size of firm via revenues. However, we did introduce revenues explicitly to the regression to control for firm size.

The respondents rated the importance of each barrier/question on a scale from 0 to 3 based on its perceived influence in the firm on the implementation of energy-efficient technologies. If a barrier's influence was strong, it was given 3 points, 2 points were given for considerable influence, and 1 point was assigned for little influence. If a barrier had no influence, it was given 0 points, and if it did not apply for a firm, it was marked as "No answer/Not applicable." The 25 questions pertaining to the different barriers are depicted in Table 1, Appendix A.

We reduced the dimensionality of the analysis using factor analysis tools. While using principal components analysis,[5] we reduced the number of variables from 25 to 7 and increased precision. We use the rule of thumb that requires the eigenvalue to be greater than 1 for the factor to be included in the empirical analysis.[6] The results of the principal components analysis are depicted in Appendix B. We obtained one common factor with an eigenvalue greater than 1 for each of the barriers analyzed (Table 1). Using the appropriate loading factors, we then calculated the covariates of the various groups of barriers investigated.

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ot included in the stylized model.

loys orthogonal transformation to convert observations of correlated variables (variables that belong to a certain group – e.g., financial barriers) into a set of values of linearly uncorrelated variables that are called principal components. It is used in macroeconomics to aggregate multi-dimension indicators and to clean the noise from observed series in the panel, which is poorly correlated with the rest of the panel (e.g., Avesani et al., 2006; Forni et al., 2000). It has also being applied to complex datasets, which included multiple indicators to construct social capital indexes (Sabatini, 2005). For more on the asymptotic characteristics of factor analysis, see Bai (2003).

[6] The eigenvalue is proportional to the portion of the sum of the squared distances of the points from their multidimensional mean. The principal components analysis essentially rotates the set of points around their mean to align with the principal components. This moves as much of the variance as possible (using an orthogonal transformation) into the first few dimensions. The values in the remaining dimensions tend to be small and may be dropped with minimal loss of information.

Our empirical model also includes the following firm characteristics (Table 1): annual revenues, the share of energy costs to the firm relative to total production costs, a dummy variable that equals 1 if the facility is rented and 0 otherwise, an ownership dummy that equals 1 if the firm is domestic and privately owned and 0 otherwise, and an ownership dummy that equals 1 if the firm is foreign owned and 0 otherwise.

Table 1. Data summary.

Variable	Observations	Mean	Std. Dev.	Min	Max
Dependent variable					
Invest	389	0.93	0.63	0	2
Firm characteristics					
Annual revenues	334	2.73	1.64	1	8
Share of energy costs	316	11.43	10.21	0.3	70
Private ownership	491	0.69	0.46	0	1
Foreign ownership	490	0.03	0.17	0	1
Facility rented	509	0.18	0.38	0	1
Barriers to the adoption of energy-efficient measures					
Financial barriers	356	6.58	2.88	0	14.59
Hidden costs barriers	420	3.76	2.55	0	11.82
Energy costs	443	0.90	1.04	0	3
Split barriers	382	1.03	1.56	0	5.50
Knowledge barriers	433	3.67	3.45	0	12.39
Existing laws and regulation	296	4.83	2.88	0	10.72
Firm's bureaucracy	401	1.45	1.72	0	7.11

3.3 The statistical model

The parallel lines assumption states that parameters are the same across the different categories. The assumption suggests that the correlation between independent variables and the dependent variable is not affected by the dependent variable's categories, (i.e., the dependent variable's categories are parallel to one another). However, because this assumption is usually violated when analyzing complex surveys, and because the ordinal response of the questionnaire implicitly captures ever-increasing levels of investment in energy-efficient technologies, we employ the GOL model (Williamson, 2006).[7] Because we aggregate the investment response variable to three categories (0, 1, and 2), the GOL model yields two response functions (i.e., for categories 0 and 1).

Let β_0 and β_1 denote the vector of parameters of the response function estimated for investment categories 0 and 1, respectively. Let *x* denote the vector of regressors, and assume *F(.)* the cumulative distribution function. Then, the probability that investment will take the value 0, 1, or 2 is equal to

$$\boldsymbol{Prob(investment = 0) = F(-x\beta_0)}$$

$$\boldsymbol{Prob(investment = 1) = F(-x\beta_1) - F(-x\beta_0)}$$

$$\boldsymbol{Prob(investment = 2) = 1 - F(-x\beta_1)}$$

Assuming a logistic cumulative distribution function allows the interpretation of the GOL model in terms of logits.[8]

Each set of coefficients can be interpreted as those of a binary logit regression. The first set of response function parameters can be interpreted as the outcome of binary regression where the dependent variable's categories are either no investment *or* positive investments (i.e., 0 *versus* 1 or 2). On the other hand, the second response function parameters can be interpreted as the parameters of a binary logit regression where the dependent variable's categories are either null to some investment *or* large investments (beyond $250,000 US in the last 5 years), that is, 0 and 1 *versus* 2.

When presenting the results, we used an alternative but equivalent presentation of the parameters of the GOL model; instead of assuming 2 sets of βs, we assumed only one set of coefficients, namely, *Beta*. We also assumed a second set of coefficients, *Gamma*. If the null hypothesis that the specific Gamma parameter equals 0 cannot be rejected, then we assumed the

[7] A key problem with the cumulative logit model is the assumption of parallel lines. This key assumption is often violated; that is, one or more of the coefficients of the regressors differs across the various categories. The GOL model relaxes the parallel lines assumption and generalizes the cumulative logit models.

[8] Because probabilities are constrained to be in the range of [0,1], the generalized ordered logit model imposes explicit restrictions on the range of the *x* variables:

$$\boldsymbol{x\beta_1 \geq x\beta_0}$$

parallel line assumption held and set the relevant Gamma parameter to zero. However, if we reject the hypothesis that the value of the Gamma parameter is 0 at a 5% significance level, then we report the parameter and the parallel line assumption is violated for this specific parameter.[9] This alternative presentation suggests that the coefficient of the specific β_0 parameter equals the relevant Beta parameter, whereas the coefficient of the specific β_1 parameter equals the sum of the relevant Beta and Gamma parameters.

3.4 The model's specifications

In developing the empirical model, we follow Hosmer and Lemeshow's (2000) incremental process. Initially, we performed a bivariate analysis of the relationship of the dependent variable investment and each of the individual regressor candidates, where each specification is defined by its set of regressor candidates. We then selected variables associated with investment whose coefficient differs from 0 at a significance level of less than 0.25 (the output of the bivariate regression is presented in Appendix C).

The next step in developing the model's specification includes the assessment of the validity of the parallel lines assumption. Because the data are survey data, the likelihood ratio is not appropriate (Williams, 2005). We, therefore, use an iterative process to evaluate the validity of the parallel lines assumption at a 5% significance level (Williams, 2006). The analysis suggests that annual revenues, being foreign owned, and knowledge barriers do not meet the parallel lines assumption but other variables do. The Wald chi-squared statistic of the model (i.e., model I in Table 2) is 46.69.

In addition to the aforementioned model (Model I in Table 2), we estimated other specifications including one where hidden costs were explicitly included in the regressor candidates set (Model II in Table 2). We used the adjusted Wald test, as well as the Bonferroni adjustment (Korn & Graubard, 1990), to evaluate the null hypothesis that some of Model II's parameters are zero (private ownership, rented facility, and hidden costs).[10] The Wald test resulted in a test statistic of F=3.14 and P-value of 0.018, whereas the Bonferroni adjustment

[9] While focusing on the baseline model, assuming a 10% significance level (or a 1% significance level), instead of a 5% significance level, would not change our conclusion that the parallel line assumption is violated.

[10] When using survey data, the assumption that observations are independent of each other may be violated. Therefore, we cannot use the LR test, BIC, and the AIC. However, we can compute the F statistic and the t statistic and perform the Wald test instead.

yielded F=3.04 and P-value of 0.021. Thus, we could not reject the null hypothesis that yields the more parsimonious specifications of Model I at a 10% significance level. Although we chose model I, we used the other models (Model II and others not reported because of space constraints) to better understand the data.

3.5 The empirical analysis

As noted above, when presenting the results, we used an alternative but equivalent presentation of the parameters of the GOL model. The alternative presentation suggests that the coefficient of the specific β parameter equals the sum of the relevant Beta and Gamma parameters. For example, (see Table 2, model I)

$$\beta_0(foreign\ owned) = 12.69 \text{ but } \beta_1(foreign\ owned) = 14.16 - 12.53 = 1.62; \text{ and}$$

$$\beta_0(financial\ barriers) = \beta_1(financial\ barriers) = -0.14.$$

Finally, the Alpha variables are simply the cutpoints, i.e., the negative of the constant of the relevant response categories: while *Constant (category 0)* is the cutpoint when comparing no investment (category 0) with positive investment (categories 1 or 2); *Constant (category 1)* is the cutpoint when comparing no to medium levels of investment (categories 0 or 1) with large investments (category 2).

*Table 2***.** *The estimated parameters of the (generalized) ordered logit model.*

Variables	Ordered Logit Model	The GOL Baseline Model: Model I	The GOL Alternative Model: Model II
Beta			
Revenues	0.38** (0.18)	0.10 (0.18)	-0.31 (0.19)
Energy expenditure	0.03 (0.02)	0.04 (0.03)	0.05* (0.02)
Private ownership	-0.14 (0.49)		-0.37 (0.60)
Foreign owned	2.57** (0.89)	14.16*** (0.72)	14.37*** (0.95)
Rented facility	-0.50 (0.58)		-0.42 (0.53)
Financial barriers	-0.24** (0.10)	-0.14 (0.10)	-0.22** (0.10)
Split barriers	0.18 (0.26)	0.10 (0.28)	0.04 (0.34)
Knowledge barriers	-0.18* (0.10)	-0.33** (0.16)	-0.37* (0.20)

Hidden costs	0.53***		-0.08
	(0.16)		(0.24)
Hidden costs and mandatory energy audit		0.09***	0.10
		(0.04)	(0.06)
Low priority for energy costs	-0.20	-0.07	0.51
	(0.43)	(0.47)	(0.68)
Firm's bureaucracy	-0.09	-0.11	-0.16
	(0.19)	(0.16)	(0.14)
Gamma			
Revenues		0.64***	
		(0.16)	
Foreign owned		-12.53***	-11.30***
		(1.15)	(1.39)
Knowledge barriers		-0.48***	-0.59**
		(0.17)	(0.25)
Hidden costs			0.71***
			(0.23)
Low priority for energy costs			-1.39**
			(0.61)
Alpha			
Constant (category 0)	-0.95	1.52	1.82*
	(0.81)	(0.94)	(1.14)
Constant (category 1)	-3.01***	-2.61***	-2.12**
	(0.92)	(0.93)	(1.06)
Statistics			
N	97	97	97
F	3.32	46.65	37.82

Legend: * p<.1; ** p<.05; *** p<.001. Numbers in parenthesis denote standard errors.

3.5.1 Economic barriers

Financial Barriers: Financial barriers quantify the importance of upfront capital costs, risk, and the opportunity cost of the adoption of energy-efficient technologies. The Model II coefficient of the financial barriers equals -0.22 and is statistically different from 0 at a 5% significance level ($\beta_0(financial\ barriers) = -0.22$). Part of the effect of upfront costs might also be observed in firms' revenues parameter. The effect of revenues on high investment levels is large. The parameter is significant at the 1% level, and an increase of 1 unit in the revenue category results in the odds of a high investment compared to a low investment changing by a factor of 2.1. Large firms are more likely to make large investments in energy-efficient technologies than firms that are more capital constrained. When analyzing the raw data, the industrial sector ranks various financial barriers higher than the commercial sector, although the differences are not large.

Furthermore, firms rank high upfront costs as the most important factor impeding adoption of energy-efficient technologies (i.e., I in Eq. (1)). The statistical analysis finds evidence that supports this observation. However, the statistical analysis suggests that it is likelier to hinder small firms' investment in energy-efficient technologies.

While Worrell (2009) found that financial barriers limit investment in energy-efficient technologies, Carpenter and Chester (1984) did not. Carpenter and Chester (1984) analyzed the conservation tax credits of the early 1980s in the U.S. and found that although 86% of those surveyed knew about the credit, only 35% used it, and of those firms that used it, 94% of investments made in energy efficiency would have been made regardless of the financial incentives (e.g., in the absence of policy).

Hidden costs: Hidden costs prevent the scaling up of energy-efficient technologies. Similar to upfront costs and financial barriers, hidden costs may yield higher costs and thus less adoption; that is, a higher H in Eq. (1) results in fewer firms benefiting from the adoption of energy-efficient technologies. The raw data suggest that installation of energy-efficient technologies needs substantial reconfiguration of production processes and that industrial firms do not trust new devices. However, we cannot reject the null hypothesis that hidden costs do not hamper adoption of energy-efficient technologies at a 10% significance level (the Wald test, as well as the Bonferroni adjusted Wald test, rejects Model II in favor of Model I – the difference between the two models being the initial set of regressor candidates).

Because preliminary analysis suggests that missing observations of hidden costs are likelier with firms that have undergone a mandatory energy audit, we introduced an interaction term between hidden costs and a dummy variable that equals 1 if the firm has undergone a mandatory energy audit and 0 otherwise. The analysis rejects the hypothesis that the interaction term equals 0 at a 1% significance level (Model I in Table 2).

Energy costs and their priority for the firm: Energy costs play an important role, as the literature predicts (Gillingham et al., 2009). Hughes (1991) suggested that the energy sector is important to Eastern European countries for two reasons: Eastern European countries have higher energy prices than countries with equivalent levels of income and Eastern European countries are also some of the most energy-intensive economies in the world.[11] On average, the firms surveyed reveal that they would decrease their energy costs by one third if there were no barriers to adopting energy-efficient technologies. The share of energy expenditure of total cost is significant at the 10% significance level in the baseline model (Model I in Table 2). That is, the higher is $E_0 p_e$ in Eq. (1), the more likely a firm is to adopt energy-efficient technology.

3.5.2 Behavioral and information barriers

Split incentive barriers: Split barriers combine barriers that show the influence of splitting the responsibility of using energy resources with another party (see Appendix A). However, the analysis does not find support for split incentive barriers and does not reject the null hypothesis that the split barrier parameter equals 0 at a 10% significance level (however, we should be careful in interpreting this result because in the sample the number of firms whose bills are paid by a building or the owner facility is only 3.4% for commercial firms and 0.6% for industrial firms). The analysis also suggests that rent is not a factor that hinders the adoption of energy-efficient technologies (Table 2). The analysis does not find support for $\zeta < 1$ in Eq. (1).

Knowledge barriers: However, we found strong support for knowledge barriers impeding the adoption of energy-efficient technologies. The iterative estimation process does not support the parallel lines assumption and suggests that the effect of knowledge barriers at low investments is different (smaller) than at high investments. The analysis finds support for $\theta > 0$ (see Eq. (1)) and that θ increases with investment. When comparing categories 0 *versus* 1 and 2, the point estimate of the Beta knowledge barrier parameter is -0.33 and is significant at the 5% level (i.e., $\beta_0 = -0.33$), but when comparing categories 0 and 1 *versus* 2 the Gamma knowledge parameter is -0.48 and $\beta_1 = -0.8$ and is significant at the 1% significance level. This indicates that Ukraine loses opportunities because it lacks awareness of and experience in energy-efficient technologies. Furthermore, the negative effect on investment is more pronounced at higher levels.

How will the amount invested in energy-efficient technologies change as knowledge and awareness of the technology change? To answer this question, while holding all other variables of the sample at their means, we plot the predicted (cumulative) probabilities of the various

[11] Recall that Ukraine is very energy intensive and inefficient in its use of energy (Apergis & Payne, 2013; Ogaranko & Hubacek, 2013).

categories (i.e., categories 0, 1, and 2) in Figure 1. The figure suggests that larger knowledge barriers result in less investment in energy-efficient technologies than otherwise.

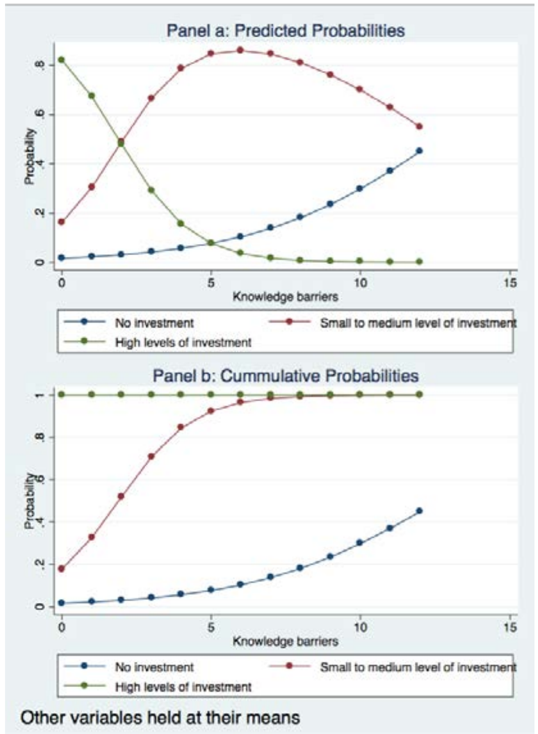

Figure 1. Knowledge barriers.

The analysis also suggests that mandatory energy audits can help firms better understand the benefits of energy-efficient technologies, yielding more adoption of these technologies; likewise, policy that incentivizes adoption of these technologies leads to their greater adoption. Several studies have tried to disentangle the effects of information provision from other factors. Newell and Siikamaki (2014) suggested that lack of relevant information can lead to significant undervaluing of energy-efficient technology and that information on economic value of the new technology is an important component affecting cost-effective decisions. Similarly, firms may fail to invest in energy-efficient technologies because they are unaware of them (Anderson & Newell, 2004; Bloom et al., 2013). Although there isn't much work on firms' adoption of energy-efficient technologies, the empirical work on residential energy-efficient programs suggests that existing programs may affect consumer behavior and may even result in some consumers relying too much on appliances with energy-efficient certifications, such as the Energy Star certification in the U.S. (Houde, 2014), thus resulting in unintended consequences.

A well thought out mechanism that assigns information provisions, however, might address such concerns (Schultz et al., 2007; Gerarden et al., 2015).

3.5.3 Institutional barriers

Existing rules and regulations: A lack of effective government policies to facilitate energy-efficient programs ranks highest among the rules and regulation factors, with an average assessment of 2.2 points. However, statistically, existing rules and regulations do not yield large barriers to the adoption of energy-efficient technologies (see Appendix C). When estimating the bivariate effect of regulation barriers on investment levels, the P-value of the parameter is 0.45. Following Hosmer and Lemeshow's (2000) incremental process resulted in existing rules and regulations not being included in the final model.

Firm's bureaucracy: Although the firm's bureaucracy barriers are included in the final model and the sign of the parameter suggests that an increase in this institutional barrier results in less adoption, we cannot reject the hypothesis that the parameter is not different than 0 at a 10% significance level. We, thus, conclude that regulatory and internal bureaucracy does not affect firms' decision whether to invest in energy-efficient technologies. That is, the statistical analysis cannot reject the null hypothesis that $\rho = 0$ in Eq. (1).

The analysis does suggest that once controlling for the other factors, foreign ownership (when the firm is 100% foreign owned) has a significant effect on the likelihood of investing in energy-efficient technologies, but this effect declines at high investment levels (Table 2).

3.6 Industrial versus commercial firms

Is the effect of the barriers the same across sectors? While using the GOL model, we increased the means of the various factors by one standard deviation and calculated the predicted probability that a firm either does not invest (investment category 0, henceforth denoted 0), makes a moderate investment (investment category 1, henceforth denoted 1), or makes a large investment (investment category 2, henceforth denoted 2). In Figure 2, we illustrate the predicted probabilities of a firm choosing a level of investment, while separating between industrial and commercial firms. For each factor that appears on the y-axis, we increase its value by one standard deviation from its mean but fix the value of other factors at their mean. We then use the estimated parameters to calculate the predicted probability that the firm will locate in a category (i.e., 0 or 1 or 2). We depict in Figure 2 the *change* in the predicted probability that a firm locates in a certain category. The change in the predicted probability is measured on the x-axis. No change in the predicted probability of a category is depicted with the category's notation locating on the zero-line (i.e., the vertical line starting at 0 on the x-axis); an increase in predicted probability is denoted via the category's notation locating to the right of the zero-line while a decrease is denoted with a notation of a category locating to the left of the zero-line.

Figure 2 suggests that revenues have a larger effect on industrial than commercial firms, although the sign of the impact is similar between the two sectors. When we increase the value of revenues by one standard deviation, the predicted probability of a firm not investing in energy-efficient technologies does not change (the 0 locates at the zero-line). However, the increase in revenues by one standard deviation results in a decline in the predicted probability of a firm making moderate investments (1 is to the left of the zero-line) but an increase for a firm making large investments (2 is to the right of the zero-line). Furthermore, the net effect on 1 and 2 is larger for the industrial sector (1 and 2 are further away from the zero-line).

Figure 2 also suggests that foreign ownership matters to industrial firms, but since there are only a few foreign firms in the commercial sector it has no statistical significance for these firms. While for the commercial sector all notations (i.e., 0, 1, and 2) are bundled around the zero-line, for the industrial sector a one standard deviation increase in the foreign factor results in the predicted probability of making no investment declining (0 locates to the left of the zero-line), but the predicted probability of making an investment increases, with a larger increase calculated for a large investment (1 and 2 are to the right of the zero-line, where 2 is further to the right than 1).

Information and its dissemination have different effects on the two sectors (Figure 2). While an increase in knowledge barriers causes commercial firms to stop investing in energy-efficient technologies (1 and 2 locate to the left of the zero-line), a similar increase leads industrial firms that would have made large investments in the technology to make smaller investments (2 locates to the left of the zero-line, but 0 and 1 locate to the right of the zero-line).

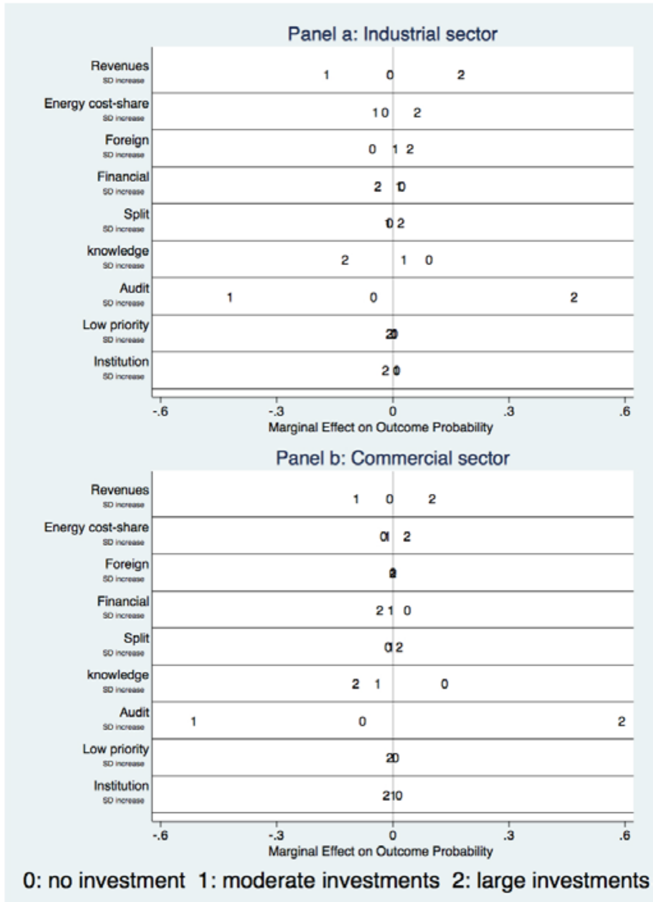

Figure 2. Marginal effect of various factors: Industrial versus commercial firms.

We found more support for differences across sectors when looking at the interaction term of hidden costs and mandatory energy audits (denoted Audit in Figure 2). Although the interaction term does not have much effect on firms that do not invest in energy-efficient technologies (although the 0 locates to the left of the zero-line, the difference is relatively small), it has a negative effect on small to moderate levels of investment (1 locates to the left of the zero-line) but a positive effect on large levels of investment (2 locates to the right of the zero-line). On average, the data suggest that commercial firms are slightly more energy intensive: The average share of energy costs in total production costs is slightly larger for commercial firms (19.9% versus 17.7%, respectively), and the empirical analysis suggests that the effect of an increase of one standard deviation of the interaction term is larger for commercial firms than industrial firms (for commercial firms, both 1 and 2 are further away from the zero-line; Figure 2).

4. Concluding remarks

This study examines energy efficiency barriers to the industrial and commercial (including public) sectors in Ukraine by conducting a survey of 509 firms throughout the country. The results from the survey are then used in empirical models to understand the importance of various barriers to the adoption of energy-efficient technologies.

The study finds that lack of knowledge and awareness are major barriers to the adoption of energy-efficient technologies, more so for large firms. Knowledge barriers likely reduce the size of investments made by industrial firms in energy-efficient technologies and result in zero investment by commercial firms. This is because the lack of awareness and information results in firms placing a low priority on energy efficiency improvements. The results suggest that information provision and energy audits help reduce this barrier. This finding is consisting with the existing literature (e.g. Thollander et al., 2007). The study also suggests that financial and economic barriers (e.g., high upfront costs of energy-efficient devices and processes, high costs of financing due mainly to higher risks perceived by financial institutions in new and emerging technologies) may further impede firms' investments in energy-efficient technologies in Ukraine, especially for small firms. We did not find firms perceiving government regulations and internal corporate bureaucracy as barriers to the adoption of energy efficient technologies. The study also suggests that an increase in energy prices would lead to greater adoption of energy-efficient technologies.

Our findings imply that improvement of energy efficiency require a major policy shift in Ukraine to reduce the barriers to energy efficient technologies. The new policies should aim to increase awareness of the benefits from energy efficient technologies among the industrial and commercial sectors. Moreover, the government can lower the financial barriers through various policy incentives, such as creation of dedicated energy efficiency improvement funds, providing guarantee (or insurance) to financial institutions that offer energy efficiency loans.

The study also finds sectorial heterogeneity to the perceived barriers to the adoption of energy efficient technologies. Such heterogeneity should be accounted for when designing policies and incentives to improve energy efficiency. In future work, we plan to seek further understanding of the importance of heterogeneity among sectors and investigate how sectorial heterogeneity might affect the design of energy efficiency policies and incentives.

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Appendix A:

Table 1A: Specific questions asked to analyze energy efficiency barriers

1) Economic barriers	**1.1) Financial barriers** **High upfront costs**: Are upfront capital costs of energy efficient appliances and devices high? **Lack of capital**: Do financial institutions (Banks and other financial institutions) perceive energy efficiency investment as risky and therefore charge high premium? **Low opportunity costs**: Are there other priorities for capital investment, which can produce high returns? **Low opportunity costs of appliances to be replaced**: Is there any resale value of the replaced appliances, which still has a long operational life? **Long payback period:** Is payback period of efficient appliances/devices too long to discourage their implementation?
	1.2) Hidden costs **Skilled personnel:** Lack of skilled personnel to handle the efficient devices and processes, especially in their maintenance **Supplies:** Lack of local supplies for equipment parts and very expensive purchasing from abroad, as well as long lead time to get equipment parts **Reconfiguration:** Installation of energy efficiency measures needs substantial reconfiguration of production process **Malfunction and poor performance:** Higher probability of malfunction or poor performance thereby disrupting production process
	1.3) Low energy costs **Low priority:** Low priority of the firm to reduce energy consumption; energy cost is not a big component of production costs
2) Behavioral and informational barriers	**2.1) Split incentives** **Bills paid by landlord:** No incentives for the firm to reduce energy consumption as energy bills are paid by building/facility owners **Split bills:** No incentives for the firm to reduce energy consumption as energy bills are split among the building/facility tenants
	2.2) Knowledge, information and experience **Metering:** Lack of gas, electric and heat metering **Awareness:** Lack of awareness of the availability and/or benefits of deploying energy efficient processes and devices **Information:** Difficulties with obtaining necessary information **Confidence:** Lack of confidence on energy efficient devices and processes (they do not deliver the services at the level their promoters advocate)

	Experience: Lack of experience in energy efficiency measures
3) Institutional barriers	**3.1) Existing Rules and Regulation** **Government permits:** Need to obtain government permits to deploy energy efficient devices and processes **Property rights:** Lack of legal protection of property rights **Policy instruments:** Administrative price setting, subsidies and cross subsidies **Government policy:** Lack of effective government policies to facilitate energy efficiency programs **Unofficial payments:** Unofficial payments demanded to receive government permits
	3.2) Firm's bureaucracy barriers **Decision chain:** Long decision chain on the firm **The future:** Uncertainty about the firm's future **Conflict of interest:** Conflict of interests inside the firm

Appendix B:

In computing the common factor attributed to each barrier, unrotated Principle-Component methods were employed. The output of the various runs is depicted in Table 1B.a.

Table 1B-a. Principle component analysis

Financial barriers:

Number of observations	356
Factors retained	1
Number of parameters	5

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	2.68267	1.97536	0.5365	0.5365
Factor2	0.70732	0.03498	0.1415	0.678
Factor3	0.67234	0.13459	0.1345	0.8125
Factor4	0.53776	0.13785	0.1076	0.92
Factor5	0.39991	.	0.08	1

Chi2(10)= 457.19

Split barriers:

Number of observations	382
Factors retained	1
Number of parameters	1

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	1.68226	1.36452	0.8411	0.8411
Factor2	0.31774	.	0.1589	1

chi2(10)= 238.34

Information and knowledge barriers:

Number of observations	433
Factors retained	1
Number of parameters	5

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	3.41871	2.84219	0.6837	0.6837
Factor2	0.57652	0.13668	0.1153	0.799
Factor3	0.43985	0.08195	0.088	0.887
Factor4	0.35789	0.15086	0.0716	0.9586
Factor5	0.20703	.	0.0414	1

chi2(10)= 1181.82

Hidden costs:

Number of observations	420
Factors retained	1
Number of parameters	4

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	2.31472	1.56538	0.5787	0.5787
Factor2	0.74934	0.2142	0.1873	0.766
Factor3	0.53514	0.13434	0.1338	0.8998
Factor4	0.4008	.	0.1002	1

chi2(10)= 413.15

Existing rules and regulations:

Number of observations	296
Factors retained	1
Number of parameters	5

Factor	Eigenvalue	Difference	Proportion	Cumulative

Factor1	2.57632	1.66628	0.5153	0.5153
Factor2	0.91004	0.31833	0.182	0.6973
Factor3	0.59171	0.07042	0.1183	0.8156
Factor4	0.52128	0.12064	0.1043	0.9199
Factor5	0.40065	.	0.0801	1

chi2(10)= 363.58

Firm's administrative barriers:

Number of observations	401
Factors retained	1
Number of parameters	3

Factor	Eigenvalue	Difference	Proportion	Cumulative
Factor1	1.88518	1.19138	0.6284	0.6284
Factor2	0.69381	0.27279	0.2313	0.8597
Factor3	0.42101	.	0.1403	1

chi2(10)= 238.16

We also obtained the extracted sum of the squared loading (Table 1B-b), and use the loading coefficients to calculate the factor that we employ in the empirical analysis.

Table 1B-b. Factor loading (pattern matrix) and unique variance

Financial barriers

Variable	Loading coefficient	Uniqueness
High Up front costs	0.7184	0.484
Lack of Capital	0.7952	0.3677
Low opportunity cost	0.7205	0.4809
Zero or very small monetary value	0.723	0.4773
Long pay back period	0.7018	0.5074

Split barriers

Variable	Loading coefficient	Uniqueness
Energy bills paid by building/facility owner	0.9171	0.1589

Variable	Loading coefficient	Uniqueness
Energy bills shared among building/facility owner and firm	0.9171	0.1589
Information and knowledge barriers		
Variable	**Loading coefficient**	**Uniqueness**
No metering	0.7696	0.4077
Lack of awareness	0.8895	0.2088
Difficulty obtaining information	0.8623	0.2564
Lack of confidence in these measures	0.8003	0.3596
Lack of experience	0.8069	0.3489
Hidden costs		
Variable	**Loading coefficient**	**Uniqueness**
Skilled labor	0.7026	0.5064
Expensive imports and lack of domestic supply	0.7938	0.3699
Requires substantial changes to the production process	0.8116	0.3413
High probability of malfunction	0.7296	0.4676
Existing rules and regulations		
Variable	**Loading coefficient**	**Uniqueness**
Government permits required	0.7873	0.3802
Lack of property rights protection	0.7467	0.4425
Administrative price setting	0.7174	0.4853
Government policy not effective	0.5878	0.6544
Unofficial payments demanded	0.7341	0.4612
Firm's administrative barriers		

Variable	Loading coefficient	Uniqueness
Long decision chains	0.7044	0.5039
Uncertainty about firm's future	0.8139	0.3375
Conflict of interest inside the firm	0.8524	0.2734

Appendix C:

Table 1C depicts the bivariate regressions of the various variables.

Table 1C. The bivariate regressors

	Coefficient	Std. Err.	t	P>t
Investment-revenues				
Revenues	0.52	0.08	6.88	0.00
Cutpoint 1	0.05	0.16	0.34	0.73
Cutpoint 2	2.98	0.23	12.98	0.00
Investment - energy cost share				
Energy cost share	-0.02	0.01	-2.71	0.01
Cutpoint 1	-1.55	0.18	-8.82	0.00
Cutpoint 2	-0.82	0.16	5.01	0.57
Investment - private ownership				
Private Ownership	-0.38	0.12	-3.24	0.00
Cutpoint 1	-1.43	0.10	-14.84	0.00
Cutpoint 2	1.06	0.10	10.69	0.00
Investment - financial barriers				
Financial Barriers	-0.17	0.04	-4.90	0.00
Cutpoint 1	-2.25	0.29	-7.82	0.00
Cutpoint 2	0.17	0.26	0.64	0.52
Investment - split barriers				
Split barriers	-0.24	0.06	-4.27	0.00
Cutpoint 1	-1.47	0.13	-11.08	0.00
Cutpoint 2	1.30	0.14	9.23	0.00
Investment - knowledge barriers				
Knowledge barriers	-0.18	0.02	-7.61	0.00
Cutpoint 1	-2.02	0.15	-13.32	0.00

Cutpoint 2	0.63	0.12	5.08	0.00
Investment – hidden costs barriers				
Technical barriers	0.05	0.03	1.76	0.08
Cutpoint 1	-1.14	0.14	-8.09	0.00
Cutpoint 2	1.35	0.15	8.98	0.00
Investment - existing rules and regulations				
Existing rules and regulations	-0.02	0.03	-0.76	**0.45**
Cutpoint 1	-1.22	0.20	-6.02	0.00
Cutpoint 2	0.97	0.21	4.64	0.00
Investment - low priority of energy prices				
Low priority of energy prices	-0.24	0.06	-3.99	0.00
Cutpoint 1	-1.44	0.11	-13.75	0.00
Cutpoint 2	1.01	0.11	9.48	0.00
Investment - firm's bureaucracy				
Firm's bureaucracy	-0.06	0.05	-1.24	0.22
Cutpoint 1	-1.50	0.13	-11.18	0.00
Cutpoint 2	1.15	0.13	8.67	0.00
Investment - foreign owned				
Foreign owned	1.35	0.32	4.21	0.00
Cutpoint 1	-1.13	0.07	-16.60	0.00
Cutpoint 2	1.36	0.08	16.82	0.00
Investment - rent				
Rent	-0.72	0.12	-5.96	0.00
Cutpoint 1	-1.30	0.08	-16.98	0.00
Cutpoint 2	1.20	0.08	14.85	0.00