ESSAYS ON GREEN ENERGY POLICIES IN THAILAND

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Economics – Doctor of Philosophy

2015

ABSTRACT

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Rural electrification is a major tool that developing countries use to foster economic development. However, grid-line electrification in remote rural areas is often excessively costly, or faces environmental challenges. For these reasons, off-grid electrification, such as solar or wind power, may be the only feasible alternative in many isolated rural areas. In Chapter 1, I examine the impact of the solar power initiative for rural electrification on economic development by studying the effect of the Solar Home System Project that Thailand's government implemented during the time period 2004-2006. I exploit variation in the year of the solar installations across households to identify the program's causal effects using household-level panel data, which allows me to control for household fixed effects, trends, and province-year effects. I find that solar units increase household income by 6.9%. This result is robust to other identification strategies, such as lagged dependent variable, propensity score reweighting, and differences-in-differences with propensity score matching. I also apply a back-of-the-envelope calculation to estimate the costs and benefits of the program. I find that the net present value of this project is about 1 billion baht or $25 million.

Since the growing concern for climate change in the 1990s, policymakers around the world have been enthusiastically supporting a wide range of incentive mechanisms for renewable energy use, including in the electric power sector. In chapter 2, I use a technology-specific subsidy program for small electricity producers in Thailand to understand the response of producers to subsidy incentives. In 2009, the Thai government adjusted the subsidy policy to

favor a relatively small power plant. The production subsidy for electricity generators that have less than 1MW of capacity is higher than the subsidy for generators that have just over 1MW of capacity. Since the total subsidy is a step function with a “notch” at 1MW, power producers who plan to build a plant near 1 MW will have an incentive to respond strategically by building a plant on the side of the notch with a higher subsidy. I develop a structural model of bunching to understand the linkage between the subsidy policy and power plant producers’ behavior. Then, I use a test developed by McCrary (2008) to examine the distribution of power plant size for electricity producers subject to the subsidy policy in 2009. I find evidence of bunching around the notch. A falsification test shows that similar bunching does not exist in the distribution of plant size built before the introduction of the notched subsidy payment.

In the final chapter, I examine the impact of the first car buyer tax rebate program in Thailand on the share of eligible cars and eco-car sales. Province level data of monthly new vehicle registrations by vehicle model during 2007-2012 are employed in the analysis in this study. This panel data set allows me to control for vehicle model and province-time fixed effects when examining the relationship between the program and share of vehicle sales. The estimation results indicate an 18% increase in the share of eligible cars sales after the introduction of the program in September 2011. However, the share of eco-car sales is unaffected by the program.

Go Green!

ACKNOWLEDGMENTS

During my journey to complete this dissertation, I have received support and encouragement from a great number of people. I would like to express the deepest appreciation to my advisor, Soren Anderson, for his invaluable guidance, caring, patience, support and encouragement. His comments broadened and deepened my view. His advice guided me in the right direction and he perpetually encouraged me to improve my work. He helped me immensely at every stage and was always available whenever I had questions. I would also like to thank my other committee members: Todd Elder, Christian Ahlin, and Songqing Jin for their useful comments and great interest in my work.

I am very grateful to the Royal Thai Government for providing me the scholarship and the opportunity to pursue my doctoral degree. Many thanks to all my friends at MSU, especially Nakarin Amares, Luke Chu, Seunghwa Rho and Yu Sun for their academic and emotional support. I appreciate their invaluable friendship.

My heartfelt appreciation goes to my parents for their understanding, encouragement and endurance during the years. Finally, thanks to Jane for her persistent patience and love.

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CHAPTER 1

Rural Electrification and Development: Evaluating Thailand's Solar Power Initiative

1. Introduction

Electricity is widely considered to be essential to economic development, and areas without electricity have far lower living standards (World Bank 2002). However, the 2009 world energy outlook reports that the electrification rate is only 60.2% in rural areas of developing countries. In response, many development programs focus on rural electrification. Electric lighting can improve quality of life by facilitating household production and leisure activity in the evening and by reducing time spent searching for firewood or other fuel sources. Lighting can similarly improve educational outcomes by allowing children to study at night after school. Electric lighting can improve health by reducing indoor pollution and burn injuries, especially among children, from kerosene lamps and candles (Meier et al. 2010). In addition, when used to power radios and televisions, electricity provides access to valuable entertainment and information sources. Finally, electricity can be used to charge cell phone and computer batteries, thereby empowering the rural poor by increasing access to knowledge and communication technologies. Thus, many developing countries include rural electrification in their development plans, hoping to break the cycle of poverty and spur economic growth.

Few studies have attempted to quantify the benefits of rural electrification (Bernard 2010), and most of these studies have only investigated the effects of expanding the electrical grid to new areas (Dinkelman 2011; Khandker, Barnes, Samad, and Minh 2009; Lipscomb, Mobarak and Barham 2013). However, grid-line electrification in remote rural areas is often constrained by difficult terrain, low population density, and distance to existing electric power plants. In addition, new coal, natural gas, or nuclear power plants in rural areas can bring pollution problems themselves, and many proposals to build new power plants are rejected by local residents. For these reasons, off-grid electrification, such as solar or wind power, may be the only feasible alternative in many isolated rural areas.

Several previous studies attempt to estimate the effects of rural electrification in developing countries. Dinkelman (2011) finds that female employment increases in the KwaZulu-Natal province of South Africa, while Lipscomb, Mobarak, and Barham (2013) finds similar results in Brazil. Lighting allows women to perform household tasks in the evening and work outside the home during the day. In addition, several studies find that electrification decreases fertility (Peters and Vance 2011, Grogan and Sadanand 2009). Lighting extends waking hours, meaning less time in bed, and radio and television provide an alternative to sex for recreation (World Bank 2008). In the case of solar electricity, however, individual household systems generate only a limited amount of electricity each day. Thus, previous empirical studies, which focus on rural electrification projects that typically provide households with unconstrained electricity access at a relatively low price, are not suitable for assessing the benefits of rural electrification through solar electricity.

I address this important research need by estimating the causal effect of providing solar electricity units to households in rural Thailand on household income. Between 2004 and 2006, the government of Thailand donated approximately 200,000 solar electricity units to individual rural households throughout the country in an unprecedented attempt to provide electricity to households living in remote areas too costly or too difficult to connect to the existing grid. I exploit the variation in the year of the solar unit installations across households to identify the program’s causal effects using household-level panel data, which allows me to control flexibly for household fixed effects, trends, and province-year effects.

Using a conventional difference-in-difference approach, I find that these solar units increased average household incomes by 6.9%. The result is robust to other identification strategies, such as lagged dependent variable, propensity score reweighting, and differences-in-differences with propensity score matching. This result is in line with previous findings in literature, although the magnitudes of the impacts are somewhat smaller, which is consistent with the fact that solar electric units generate a limited daily amount of electricity. A simple back of the envelope calculation suggests that the net present value of the program is $1 billion baht or $25 million, approximately $125 per treated household.

This paper contributes to the previous literatures by using a credible and transparent difference-in-difference identification strategy. Most of previous literatures use instrumental variables. For example, Dinkelman (2011) employs sloped terrain in south Africa as an instrument for the electricity grid. Lipscomb, Mobarak, and Barham (2013) use simulated engineering costs for hydroelectric dams in Brazil as an instrument for electricity access. In contrast, my estimation is based on transparent difference-in-different strategy due to variation in timing of treatment for eligible households.

The results of this paper also contribute to a recent policy debate about how best to expand electricity access in rural areas: grid extensions versus off-grid solutions. As noted above, extending the grid is often excessively costly, or faces environmental challenges. In contrast, off-grid electrification is easier to install, less costly, and generates less pollution. However, the sustainability of off-grid electrification is also questionable, since many of the solar units in Thailand's program or the Soccket project[1] in other developing countries were found to be

[1] Soccket is a soccer ball that is able to covert the kinetic energy from playing soccer to power a reading lamp at night. It provides enough electricity power to an LED lamp for three hours after playing soccer with the ball for thirty minutes.

damaged several years after implementation. Despite skepticism about sustainability, this study shows a positive net present value from Thailand's solar project. Therefore, off-grid electrification may be a good solution, although its cost effectiveness and sustainability needs to be verified case-by-case.

The rest of the paper is organized as follows. Section 2 discusses Thailand's solar electricity initiative. Section 3 presents a simple model to explain how solar electricity system may alter income of the household. Section 4 describes the availability of data. Section 5 discusses my identification strategy, provides descriptive statistics for the key variables, presents the econometric model, and presents my estimation results. Section 6 discusses the sustainability of the program. Section 7 provides a back-of-the-envelope calculation of the program's net present value. Section 8 concludes with a summary of my major findings.

2. Thailand's rural solar-electricity initiative

In 2004-2005, the Thai government donated approximately 200,000 solar home systems (SHSs) to individual rural households throughout Thailand. The recipients of these systems were households that could not be connected to the electric power grid due to the high cost of connection or because the households lived in nationally protected land. Every household who did not already have electricity was eligible to receive a solar panel eventually.

By providing solar electricity, the government hoped to increase access to radio and television news, thereby allowing rural households to participate more fully in the political and administrative affairs of the country, with the ultimate goal being to provide electricity for every household in the country by the year 2005. Each system provided by the Thai government consists of one 120 Watt-Peak (maximum power under ideal conditions) solar module, an inverter of at least 150 Watts, a 125 Ampere-hours battery, two 10-Watt fluorescent lamps, and a set of electrical outlets. Each complete system costs approximately 25,000 Baht or about $800.

Figure 1.1 presents a schematic of the solar electricity systems provided by the Thai government. Solar panels were installed on a separately constructed pole because the roof structures of most houses in remote areas are not strong enough to support the system, and to ensure better exposure to sunlight throughout the day. The solar panels are photovoltaic cells that produce a direct current from the radiant energy of the sun that reaches the panel. The panel is connected to a solar charger and controller, which regulates the voltage and current coming from solar panels to a standard household electrical voltage (220 volt, a standard voltage for electrical appliances in Thailand). Then, fluorescent lamps and a battery are connected to the system to serve for a basic usage and as storage devices respectively. Batteries store electricity produced during the day so that it can be used as needed at nighttime or during overcast weather. Batteries also serve to power the solar array, so that it functions at a stable voltage, since the amount of solar radiation being absorbed by the array varies throughout the day (Florida Solar Energy Center, 2006).

These systems generate about 350 to 450 Watt-hours per day. Maximum continuous power output is limited to about 150 Watts by the inverter’s capacity. Thus, the systems generate electricity sufficient to provide, for example, several hours of lighting (using two 10-Watt light bulbs) and about one hour of television per night.

The government’s goal was to provide electricity to the majority of Thailand’s 203,000 off-grid households. The program planned to install solar electricity systems in two phases over a period of two years in 2004–2005. About 153,000 systems were installed in the first phase, while about 50,000 systems were installed in the second phase.

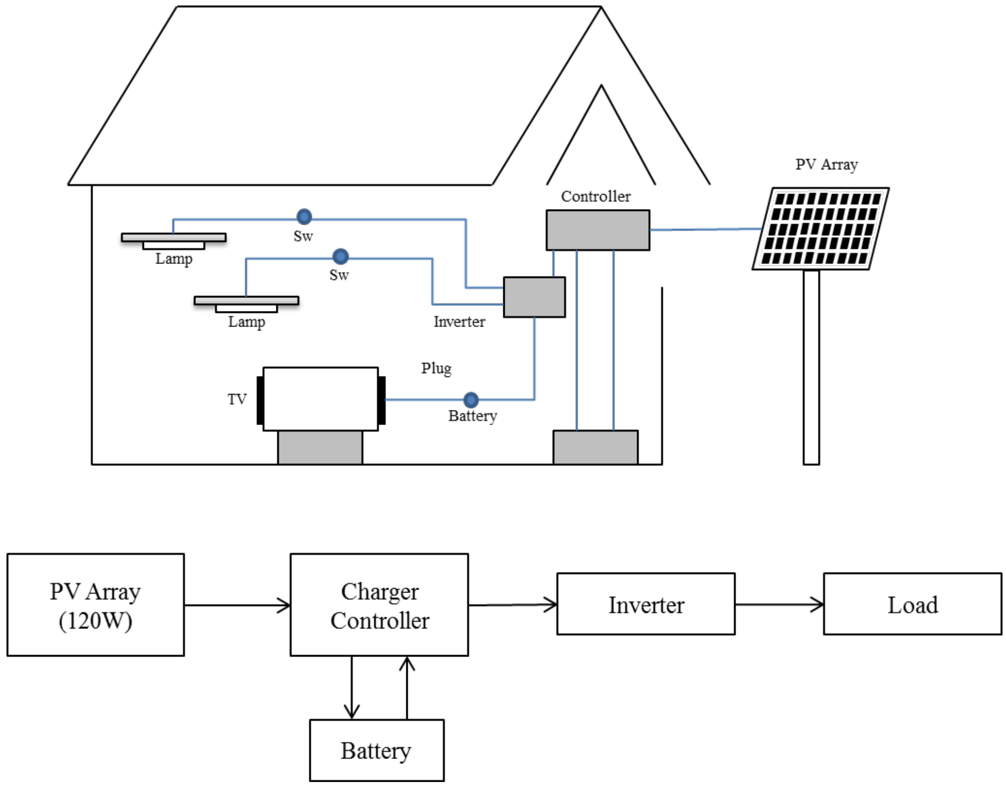

Figure 1.1: The model of SHS in Thailand
Source: Kruanpradit et al. (2004)

The actual installation was delayed and some installations were finished later than initially planned; i.e. installations for some households in Phase 1 were completed at the end of 2005, while installations for some households in Phase 2 were finished at the end of 2006. Therefore, households that obtained the solar electricity system can be categorized into 3 groups based on installation date;

1. Households that received systems in 2004 (HH04),
2. Households that received systems in 2005 (HH05), and
3. Households that received systems in 2006 (HH06).

Figure 1.2 compares the geographic distribution of HH04, HH05, and HH06.

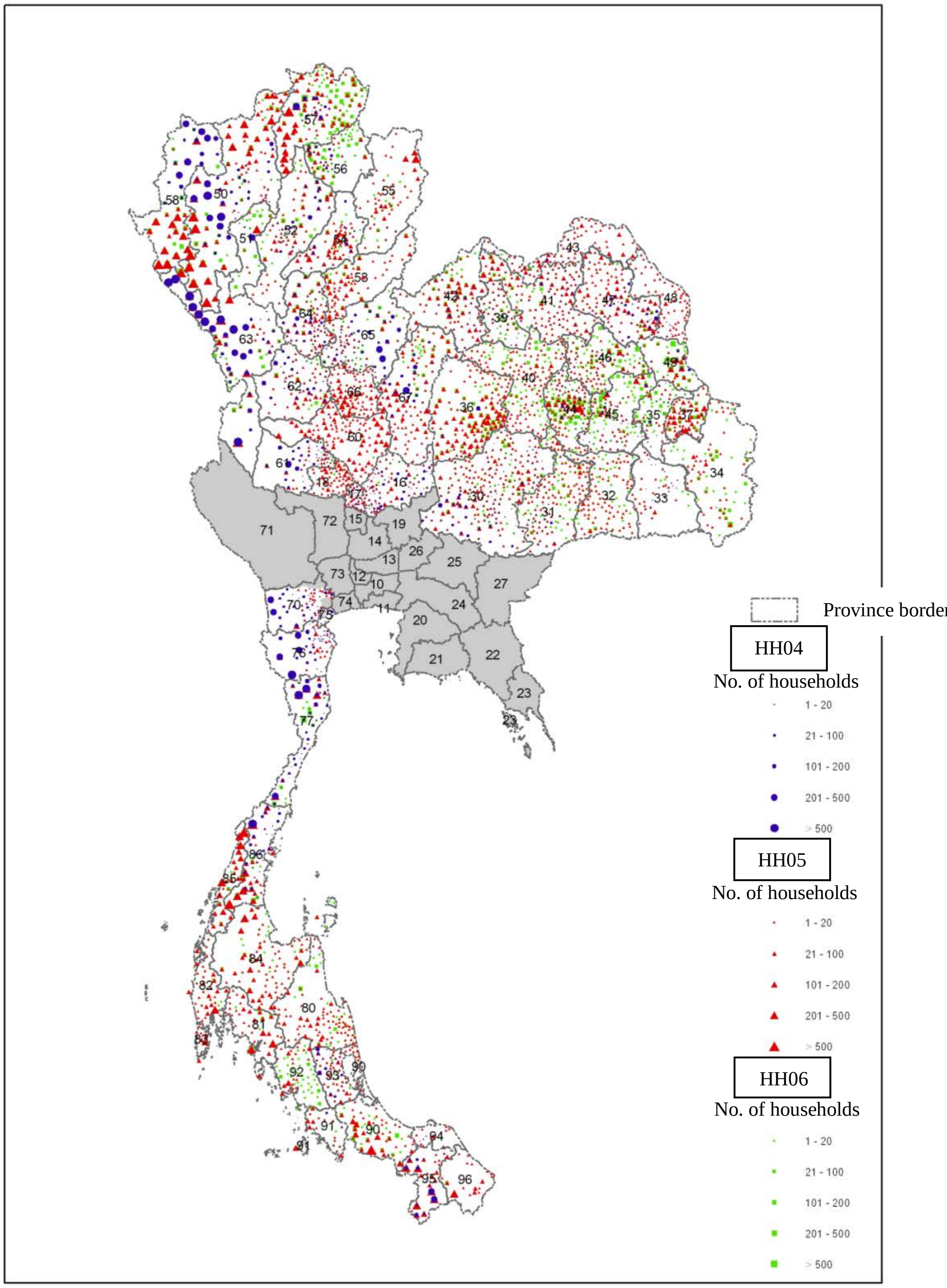

Figure 1.2: Map compares density and distribution of HH04, HH05, and HH06 at the sub-district level

Note: The shaded area is the central region for which the installation year is unavailable.

3. Theoretical effect of solar electricity on household income

This section introduces a simple model to explain how solar electricity system may alter the income of the household. For simplicity, in this model, the benefits of solar units were limited to the provision of lighting only. I do not include the benefits from using the solar electricity system to power radio and television, or to charge a cell phone battery, which the household could use to learn about new technology, ideas, commodity prices in a distant market, or the weather forecast.

Suppose household i's welfare is represented by the following utility function:

$$u_i(l_i, Y_i) = v_i(l_i) + Y_i, \quad (1)$$

where $v_i(l_i)$ is utility from leisure, l_i, with $v_i' > 0$ and $v_i'' < 0$, and Y_i is the household's income. The household's budget constraint is

$$Y_i = w_i L_i\,, \quad (2)$$

where L_i is hours worked and w_i is wage. The household's time constraints can be written as

$$24 = L_i + l_i, \qquad (3)$$

$$\text{and } L_i \ \leq T_{day} \text{ or } l_i \geq 24 - T_{day}, \qquad (4)$$

Equation (4) shows the working-time constraint due to the limitation of daylight when there is no electricity in the household, assuming T_{day} hours of light per day. For instance, a household that weaves or produces handicrafts for a living can work only under the sunlight. Thus, the maximum hours of work per day for this household is T_{day}.

If the household allocates time between work and leisure to maximize utility, under the Kuhn-Tucker conditions, there are two possible maxima. If $l_i^* \geq 24 - T_{day}$, then $v_i'(l_i^*) = w_i$. The other possible maximum is the corner solution in which $l_i^* = 24 - T_{day}$.

After the household receives the solar home system, the working-time constraint changes to

$$L \leq T_{day} + T_{shs} \text{ or} \geq 24 - T_{day} - T_{shs}, \qquad (5)$$

where T_{shs} is hours of lighting from light bulbs using electricity generated by the solar panel. With lights during the night, the length of the effective day is increased. It allows the households to prepare or fix their equipment and to make a plan for tomorrow's job[2]. This change will not alter the solution of the household whose working time constraint is not binding before getting solar panel. However, the household in corner solution before getting solar panel will decrease their optimal leisure to satisfied $v_i'(l_i^*) = w_i$ condition or choose $l_i^* = 24 - T_{day} - T_{shs}$.

Graphically, Figure 1.3a represents the tangency condition between an indifference curve and the household budget constraint when the working-time constraint is not binding. In this case, after the household receives the solar panel, the income of household will not change (staying at Y^0). Figure 1.3b illustrates the case when the working-time constraint is binding before the household receives the solar panel. The solar home system changes the budget

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[2] Faculty of Engineering and Architecture (2007) questioned sample households who received the solar unit (3,350 households all over the country) about the benefits of the program. They found that households use the lights at night to increase their household income by separating paddy, making handicrafts, preserving fruit, fertilizing, collecting insects, and repairing their farm or fishing equipment.

constraint by increasing possible working time. Thus, the income of household will increase from Y^1 to Y^2 .

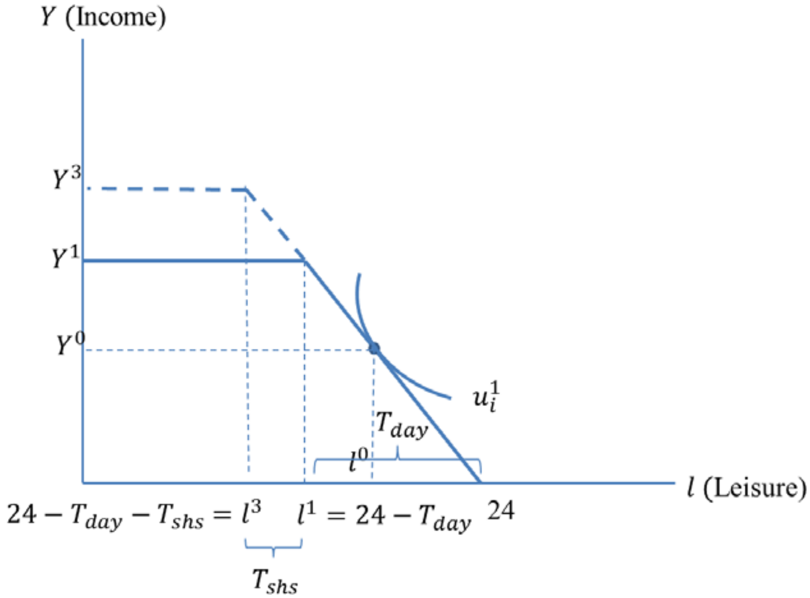

Figure 1.3a: The effect of a solar electricity system on household income: Working-time constraint is not binding

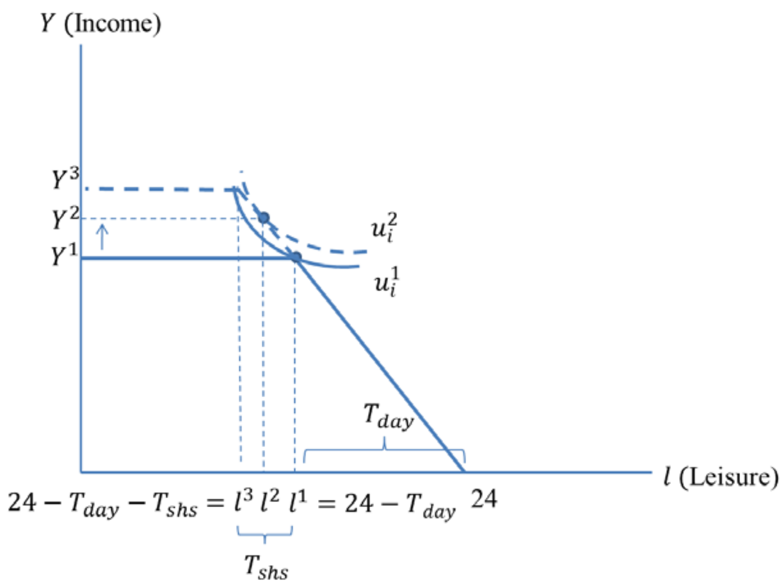

Figure 1.3b: The effect of a solar electricity system on household income: Working-time constraint is binding

4. Data availability

The data employed in this study come from two main sources: a list of the households that received a Solar Home System (SHS) from the Provincial Electricity Authority (PEA), and the socioeconomics data in the Basic Minimum Need (BMN) survey. PEA information consists of the name and address of households that acquired SHS (202,998 households), installation date, name of the solar system installer, and the hiring contract number. To compare the living standards of households before and after receiving a solar electricity system, this study matches household and installation date in the data from PEA with their socioeconomics data in the BMN survey.

The BMN survey measures the life quality of household members in different dimensions during a specific period. The BMN data are collected at the household level every year in every village all over the country (approximately 8 million households per year). Information covers every household member who lived in the house for at least 6 months of the last year. Information is generally collected in January to March about living standards during the previous year. BMN data in this study cover the period of 2001-2005. Information in BMN consists of household income, the number of pregnant women, the number and ages of children, child education, and various demographic variables and other measures of well-being.

Household addresses were used to link households across BMN surveys to generate household-level panel data on well-being for 2001-2005. These data were then matched to SHS installation dates by household address. Names were ignored in the matching process due to errors or incomplete information, such as misspelling and other typos, repeated names, and changes in household members interviewed for BMN. In the matching process, data for 43,944 households was found in at least one year.

There are several factors that influence the matching. First, all information in the central region from PEA is missing because it does not contain village name or installation date. These missing data account for about 8.44% of the total solar installations. Second, some solar units were installed in a public area, such as a religious site, temple, or school, which has no BMN data. Finally, the data contain some errors, such as strange letters in the village identification number, misspelling in a village name, missing village name, strange letters in the home number, or a home number format that was inadvertently set to a date-month format in Excel in a way that makes it impossible to recover the original house number. Most of the errors in the data come from the administrative PEA data, since PEA is not proficient in data collection and management.

Data on annual rainfall (millimeters) in each province was obtained from the National Statistics Office of Thailand. However, the information of some provinces is missing since there is no weather station in those areas. To cope with this problem, the missing data were estimated using the average annual rainfall of surrounding provinces.

5. Empirical strategies and results

To avoid selection bias problems due to the policy's non-random implementation, this study employs difference-in-differences techniques. I compare the before (2003) and after (2005) income of households that received solar panels in 2004 (HH04) and in 2006 (HH06).

Since the program was started in 2004, data in 2003 were chosen to reflect the status of households prior to when the program was implemented. There was no household that had a solar unit installed in this year. This study uses 2005 as an after program year. The reason that data in 2004 are not employed for this task is because the solar unit installations in 2004 are distributed throughout the year. The income in 2004 of HH04 incompletely reflects the impact of the solar unit. If a solar unit was installed at the beginning of the year, the income would reflect the impact of the program. However, if households received their unit late in the year, annual income of that year will not reflect the impact of the solar unit. Besides the obvious fact that households without a solar unit cannot generate electricity, upon receiving their unit, households may adapt slowly or may delay in acquiring electronic devices, such as a radio, TV, or cell phone, that would increase their productivity. Moreover, households may only learn gradually about the benefits of electricity-using devices, such as using a cell phone to sell agricultural products in a distant market for a higher price than in the local market. In addition, household production may only adjust slowly in response to lighting, perhaps because it takes time to reschedule household activities from the daytime to nighttime.

The HH04 and HH06 were selected as a treatment and control group, respectively. This study does not include HH05 in either the control or treatment group. The HH05 should not be included in the control group, since HH05 already received solar unit in 2005. I do not include HH05 in the treatment group because some households in HH05 had received the solar unit at the end of the year. As discussed above, there was an inadequate amount of time for them to learn to use the solar panel[3]. Since I used HH06, the group of households who are also eligible in the program but still did not get the installation in 2005, as a control group, the treatment and control households should share similar preprogram characteristics.

Another potential concern is the effect of other policies. If the timing of implementation of the solar units was correlated with timing of other programs, it would be hard to identify the impact of electrification program. Although there were many populist policies launched in

[3] Table A.1 in appendix shows the results of the estimation of equation (6) in section 5.2 using the full set of data during 2001-2005, including HH05.

Thailand in the past decade, there was none starting in 2004. The "one million baht one village" fund program[4], "one tambon one product" program (OTOP)[5], and micro-credit program were all started in 2001, while the "thirty-baht health care" program[6] was started in 2002. Therefore, the effect of solar unit should not be contaminated by these other programs.

5.1 Summary statistics

In order to do the empirical analysis, I use data of 14,255 households for which I have household income data in both 2003 and 2005. Table 1.1 presents the summary statistics for several key variables in the data set, classified by installation year. Panel A shows the geographic distribution of households who received a solar panel. Most of HH04 (71%) are in north region, while most of HH06 are distributed in the north and northeast regions (40% and 49% respectively).

In 2003 (Panel B), average logged real income was 11.03 for HH04, compared with an average of 11.22 for HH06. Annual rainfall (*Rain*), number of household members age 18-60 year old members (*Age 18-60*), and number of member older than 60 years (*Elder*) are higher for HH06 than in HH04. On the other hand, the number of household members (*HHmem*), number of children age 3-5 years (*Age3-5*), number of children age 6-11 years (*Age6-11*), and number of children age 12-14 years (*Age12-14*) are lower in HH06 than in HH04. The number of disabled in the household (*Disabled*) is not significantly different between HH04 and HH06. In 2005 (Panel C), average logged real income was 11.41 for HH04, compared with an average of 11.44 for HH06. The *Rain* and *Elder* variables are higher in HH06 than in HH04. On the other hand,

[4] This program was allocated roughly 1 million baht (around $33,000) to each village.

[5] This program stimulates the development of small and medium-size rural enterprises at the sub-district level.

[6] This program limits a hospital's charge to 30 baht (approximately $1).

HHmem, *Age3-5*, *Age6-11*, and *Age12-14* variables are lower in HH06 than in HH04. *Age 18-60* and *Disable* variables are not significantly different between HH04 and HH06.

The average logged real income of treated households is lower than non-treated households in both 2003 and 2005. In both type of households, average logged real income increased over time. However, it increased more in HH04 relative to their HH06 counterparts after the solar panels were installed. The relative gain (the "difference in differences") of the changes in logged real income is 0.147, implying an approximately 15% relative increase for HH04.

Further insight into this change is provided in Figure 1.4, which shows the distribution of logged income for the treated and non-treated households before and after the program. For the treatment group (HH04), there was a notable rightward shift in the distribution from 2003 to 2005. On the other hand, the density looks similar for the control group (HH06) between 2003 and 2005.

Figure 1.5 compares the trend of logged real income for treatment households (HH04) and non-treated households (HH06) before the first phase of the program arrived in 2004. When comparing 2001 and 2003, the trend of HH04 vs. HH06 looks similar for logged real income. Trends of other variables are also compared and shown in Figure A.1 in the appendix to this chapter.

I test formally for a difference in pre-treatment trends in logged real income conditional on controls by estimating the following equation:

$$Y_{it} = \alpha_0 + \alpha_1 T_{it+2} + X_{it}'\alpha + \delta_t + \mu_i + \varepsilon_{it},$$

where t is 2001 and 2003, Y_{it} is logged real income for household i in year t, T_{it+2} is the lead of the treatment variable, X_{it} is a vector of covariates that I will discuss in more detail in the next section, μ_i is a household fixed effect, and δ_t is a year effect.

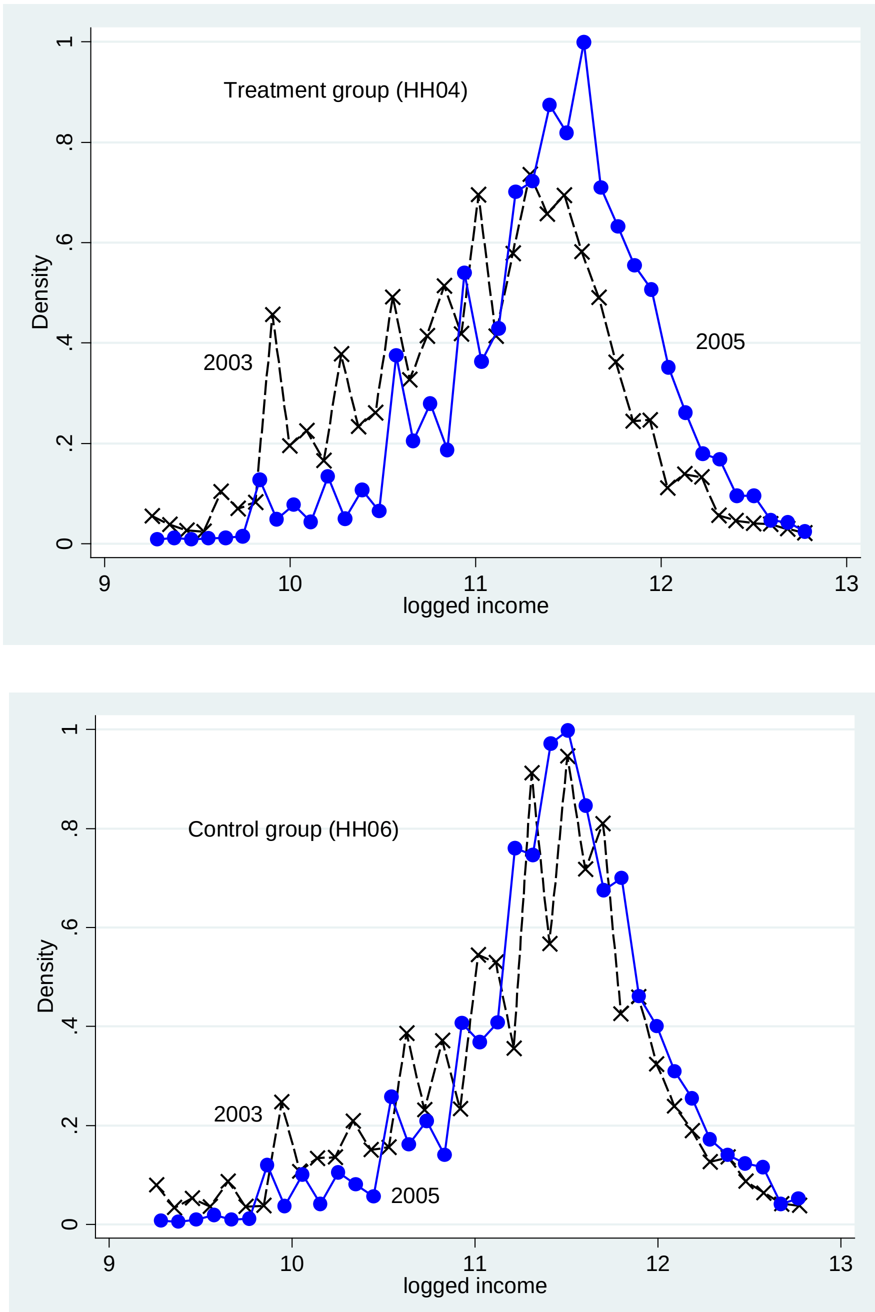

Figure 1.4: Distribution of log income for treatment and control group: Comparison of 2003 vs. 2005

Table 1.1: Summary Statistics

Variables	HH04	HH06
A. Geographic distribution of household (percentages):		
North	70.84	40.19
Northeast	7.76	48.59
South	21.39	11.21
B. Means in 2003:		
log real income	11.03	11.22
	(0.008)	(0.011)
Rain (millimeter)	1088.84	1270.13
	(2.289)	(4.731)
HHmem	4.31	4.23
	(0.022)	(0.023)
Age 18-60	2.31	2.42
	(0.014)	(0.017)
Elder	0.32	0.40
	(0.007)	(0.009)
Disabled	0.02	0.02
	(0.002)	(0.002)
Age3-5	0.26	0.19
	(0.006)	(0.006)
Age6-11	0.56	0.45
	(0.009)	(0.009)
Age12-14	0.29	0.24
	(0.006)	(0.006)
C. Means in 2005:		
log real income	11.41	11.45
	(0.006)	(0.008)
Rain (millimeter)	1249.41	1476.03
	(2.690)	(4.935)
HHmem	4.26	4.12
	(0.022)	(0.023)
Age 18-60	2.22	2.21
	(0.015)	(0.019)
Elder	0.34	0.42
	(0.007)	(0.009)
Disabled	0.02	0.02
	(0.002)	(0.003)
Age3-5	0.23	0.17
	(0.005)	(0.006)
Age6-11	0.54	0.41
	(0.009)	(0.009)
Age12-14	0.29	0.24
	(0.006)	(0.006)

Note: Standard deviations are presented in parentheses.

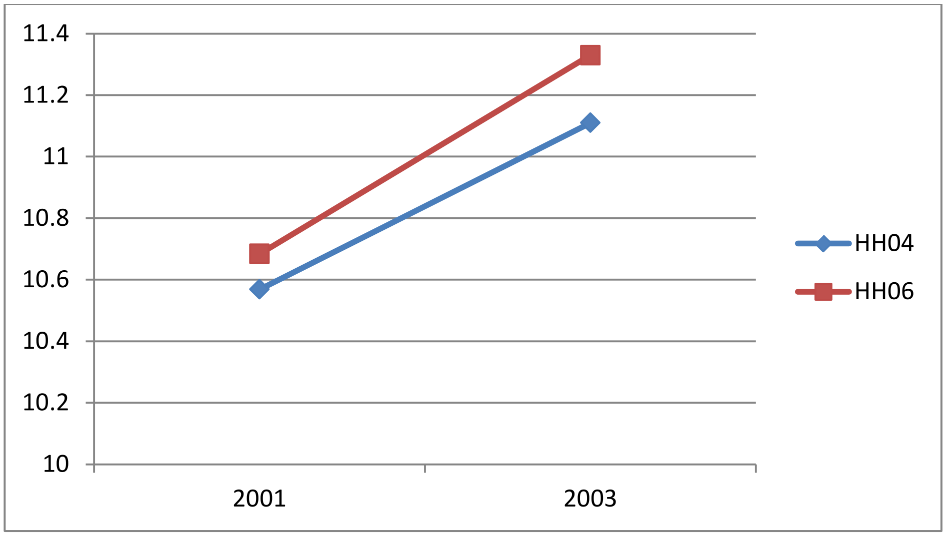

Figure 1.5: Comparing the trend of log real income between treatment and control groups before the program

Table 1.2 shows the estimates from the above equation with and without controlling for the vector of covariates. The coefficients on the leads of the treat variable are insignificant in both specifications. Thus, there is no statistically significant difference in the trend of logged income for treatment and control households before the program, conditional on controls.

Table 1.2: Test for pre-trend

VARIABLES	(1) log real inc	(2) log real inc
T_{it+2}	-0.100	-0.058
	(0.099)	(0.111)
Constant	10.509***	10.409***
	(0.032)	(0.489)
Controls	No	Yes
Year Effect	Yes	Yes
Household Effect	Yes	Yes
Observations	23,700	20,109
R-squared	0.115	0.128

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5.2 Differences in differences (DD)

The difference-in-differences estimate can be calculated within a regression framework. The estimating equation is specified as follows:

$$Y_{it} = \beta_0 + \beta_1 T_{it} + X'_{it}\,\alpha + \mu_i + \delta_t + P_{it} + \epsilon_{it}\,, \quad (6)$$

where Y_{it} is an outcome variable of interest (for example, logged real income) for household i in year t, T_{it} is an indicator variable for whether a household has received a solar unit by time period t, X_{it} is a vector of time-varying household controls, μ_i is a household effect that is constant over time, δ_t is a year effect that is constant across households, and P_{it} is the province-year effects. Province-year effects control for unobserved differences between provinces over time, such as natural disasters or recessions. Moreover, it might be the case that the solar panel installation time is correlated by province. Excluding province-year effects could therefore introduce a selection bias.

The vector of covariates (X_{it}) controls for predetermined factors affecting household outcomes that vary over time. Covariates include annual rainfall (millimeter), number of household members, number of members age 18-60; number of elder members (older than 60 years), number of disabled in the household; number of children age 3-5, number of children age 6-11, and number of children age 12-14. I do not include number of infant children because this variable is more plausibly an endogenous outcome of the treatment than the above controls.

Table 1.3 shows the estimates from equation (6) using the log of real household income as the outcome variable. The table provides estimated coefficients for the electrification indicators, control variables, time trends, and province-year dummy variables. I cluster standard errors at the province level to account for annual shocks to household income that are correlated across households in the same province, such as weather patterns that affect agricultural productivity. Thus, standard errors (in parentheses) are fully robust to heteroskedasticity, as well as serial correlation and spatial correlation both within and across households living in the same province.

Table 1.3: Baseline results

VARIABLES	(1) log real inc	(2) log real inc	(3) log real inc	(4) log real inc
T	0.147*	0.130*	0.064***	0.069**
	(0.0761)	(0.0711)	(0.021)	(0.0307)
rain		0.001***		-0.001***
		(0.0004)		(3.50e-05)
rainsq		-2.88e-07***		8.60e-08***
		(7.84e-08)		(3.67e-09)
HHmem		0.157***		0.158***
		(0.0086)		(0.0083)
Age18-60		0.019		0.013
		(0.0124)		(0.0097)
Elder		-0.009		-0.010
		(0.0149)		(0.0131)
Disabled		-0.032		-0.028
		(0.0296)		(0.0288)
Age3-5		-0.018		-0.021**
		(0.0114)		(0.0077)
Age6-11		-0.047**		-0.040**
		(0.0179)		(0.0186)
Age12-14		-0.022		-0.019
		(0.0202)		(0.0209)
Constant	11.110***	9.448***	11.300***	11.290***
	(0.0362)	(0.3730)	(0.0030)	(0.0669)
Year Effect	Yes	Yes	Yes	Yes
Household Effect	Yes	Yes	Yes	Yes
Province-year Effect	No	No	Yes	Yes
Observations	28,494	26,846	28,494	26,846
R-squared	0.166	0.257	0.142	0.343

Note: Robust standard errors in parentheses, clustered at province level.
*** p<0.01, ** p<0.05, * p<0.1

Column (1) shows the estimate from equation (6) without controlling for any covariates. This estimation is directly comparable to the simple difference-in-differences of logged income change in section 5.1. Column (2) adds eight control variables. Column (3) adds province-year effects without control variables. Column (4) adds control variables and the province-year effects. The coefficient of 0.069 on the solar electricity dummy in column (4) implies that solar electricity increases real household income by approximately 6.9%. This result aligns with the work of Khandker et al. (2009), which investigates the impacts of the World Bank financed Rural Electrification project (grid electrification) in Vietnam on household welfare using panel survey fielded in 2002 and 2005. They found that electrification increases household income by 36%. The magnitude of the impact in this study is smaller, however, which is consistent with the fact that solar electric units generate a limited daily amount of electricity.

5.2.1 Robustness tests

I check the robustness of the results in Table 1.3 using the lagged dependent variable model suggested by Angrist and Pischke (2009). Also the lagged dependent variable model accounts for the possibility of the preprogram dip problem[7]. Table 1.4 shows the estimate from the following equation:

$$Y_{it} = \beta_0 + \beta_1 TT_{it} + X'_{it}\alpha + \gamma Y_{it-2} + P_i + \epsilon_{it}, \quad (7)$$

where t is 2005, TT_{it} is an indicator for whether a household is treatment or control. Y_{it-2} is the lag of logged real income (logged real income in 2003), and P_i is the province effect.

From Table 1.4, the coefficient on the policy dummy variable is 0.062, which is about the same as the estimation of the DD model in column (4) of Table 1.3.

[7] See Ashenfelter and Card (1985).

Table 1.4: Robustness test: Lagged dependent variable

VARIABLES	log real inc
TT	0.062**
	(0.0278)
rain	-3.55e-05
	(2.60e-05)
rainsq	4.80e-09
	(5.14e-09)
HHmem	0.151***
	(0.0110)
Age18-60	0.011
	(0.0144)
Elder	-0.053***
	(0.0104)
Disabled	-0.075***
	(0.0208)
Age3-5	-0.039**
	(0.0179)
Age6-11	-0.029**
	(0.0129)
Age12-14	-0.024*
	(0.0130)
Lagged log real inc	0.242***
	(0.0306)
Constant	8.169***
	(0.3580)
Province Effect	Yes
Observations	13,685
R-squared	0.4040

Note: Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.2.2 Heterogeneity of the treatment effect

It is interesting to know whether the solar home system is similarly effective for the households in different quantiles of income, or in different regions. To examine the quantile heterogeneous effect, I create 4 sub-group samples by income in 2003 from the DD-data, and then estimate equation (6) separately for each group. I find that there is no significant impact on income for households in the bottom or top income quartiles, although the point estimate is large and positive for high income group. I find positively significant effects on middle-income households (see Table 1.5).

One possible way to explain these results is through the model in section 3. It might be the case that, before the policy, treated household in the lowest and highest income sub-groups are at an interior solution, while middle-income households are at a corner solution. If households relatively preferred leisure to income, they are probably not going to use electricity from a solar unit for working during nighttime. Then, their household income would not be affected.

To allow for heterogeneous treatment effects by region, I interact the policy variable (*T*) in equation (6) with regional dummy variables. In particular, the estimating equation is:

$$Y_{it} = \beta_0 + \beta_1 T_{it} + \beta_2 T_{it} \cdot N_i + \beta_3 T_{it} \cdot NE_i + X'_{it}\,\alpha + \mu_i + \delta_t + P_{it} + \in_{it}, \quad (8)$$

where N_i and NE_i are dummy variables indicating whether household *i* lives in the north or northeast region, respectively.

Table 1.6 provides the effect of solar units on logged real income from equation (8). The effect on household income in the north is about 10.4% higher than in the south. However, the effect in the northeast is not statistically different than in the south. These results are consistent with the fact that rural households in the north region weave or make bamboo basketry handicrafts for a living, which with lights, they can work in the night. On the other hand, rural households in the south and northeast regions mostly work in the fishing industry, on rubber plantation, or on farms, for which the small amount of extra light is not particularly helpful. Thus, households in the north gain more benefits from the change in the budget constraint due to the solar units than households in other regions.

Table 1.5: Heterogeneous treatment effects by quantile

	(1)	(2)	(3)	(4)
Percentile	less than 25	[25-50)	[50-75)	more than 75
VARIABLES	log real inc	log real inc	log real inc	log real inc
T	-0.034	0.119*	0.054*	0.108
	(0.0483)	(0.0692)	(0.0299)	(0.0703)
rain	-0.002***	-0.0003***	-0.0007***	0.0003***
	(7.30e-05)	(0.000107)	(1.55e-05)	(2.31e-05)
rainsq	5.32e-07***	4.53e-08***	1.33e-07***	-4.42e-08***
	(2.25e-08)	(1.28e-08)	(2.35e-09)	(3.73e-09)
HHmem	0.122***	0.117***	0.128***	0.117***
	(0.0217)	(0.0108)	(0.0181)	(0.0129)
Age18-60	0.045***	-0.005	0.007	0.004
	(0.0121)	(0.0155)	(0.0096)	(0.0081)
Elder	0.028	-0.009	-0.018	0.009
	(0.0235)	(0.0326)	(0.0280)	(0.0258)
Disabled	0.003	-0.040	-0.007	-0.012
	(0.0644)	(0.0380)	(0.0293)	(0.0433)
Age3-5	-0.018	-0.041*	-0.011	-0.029*
	(0.0280)	(0.0203)	(0.0268)	(0.0152)
Age6-11	-0.050***	-0.043***	-0.038**	-0.028
	(0.0180)	(0.0152)	(0.0169)	(0.0173)
Age12-14	-0.010	-0.039**	-0.023	-0.037*
	(0.0295)	(0.0191)	(0.0185)	(0.0189)
Constant	11.440***	10.820***	11.380***	10.780***
	(0.0601)	(0.126)	(0.0792)	(0.0636)
Year Effect	Yes	Yes	Yes	Yes
Household Effect	Yes	Yes	Yes	Yes
Province-year Effect	Yes	Yes	Yes	Yes
Observations	6,770	6,494	6,801	6,781
R-squared	0.6960	0.3800	0.2130	0.2410

Robust standard errors in parentheses, clustered at province level
*** p<0.01, ** p<0.05, * p<0.1

Table 1.6: Heterogeneous treatment effects by region

VARIABLES	log real inc
T	-0.001
	(0.0166)
T*N	0.105***
	(0.0375)
T*NE	-0.028
	(0.0405)
Rain	-0.0005***
	(5.23e-05)
rainsq	7.10e-08***
	(6.11e-09)
HHmem	0.157***
	(0.0082)
Age18-60	0.013
	(0.0096)
Elder	-0.009
	(0.0130)
Disabled	-0.028
	(0.0290)
Age3-5	-0.020**
	(0.0078)
Age6-11	-0.039**
	(0.0184)
Age12-14	-0.019
	(0.0208)
Constant	11.080***
	(0.0879)
Year Effect	Yes
Household Effect	Yes
Province-year Effect	Yes
Observations	26,846
R-squared	0.3430

Note: Robust standard errors in parentheses, clustered at province level
*** p<0.01, ** p<0.05, * p<0.1

5.3 Propensity score reweighted regression

To balance the observable covariates between treatment and control groups, I use the propensity score reweighted regression. In particular, the estimating equation is the following regression:

$$\Delta Y_i = \beta_0 + \beta_1 \Delta T_i + \Delta X'_i \alpha + \epsilon_i, \quad (9)$$

with weights of $1/\hat{p}(x)$ for treated households and $1/(1-\hat{p}(x))$ for controls, where $\hat{p}(x)$ is an estimator of propensity score. $\Delta Y_i, \Delta T_i,$ and ΔX_i are the differences of logged real income, the policy variable, and the control variables between 2005 and 2003 of household i.

The validity of using propensity score in impact evaluation analysis depends on the following two assumptions: unconfoundedness and overlap. Although there is no formal test for these two assumptions, the balancing test is always used as a diagnostic tool for the propensity score specification. To estimate propensity score, I used the data in 2003 to run the logit model of treatment variable on exogenous variables. The result is shown in Table B.1 in the appendix to this chapter. Note that I adjust the model specification in the logit model until the balance test under the *pscore* command in the Stata is satisfied. Table 1.7 shows that the solar unit increases household income by 4.08%

As a further robustness check, I estimate a DD with propensity score matching model. First, I matched household in 2003 using propensity score from the model in Table B.1. After that I merge them with DD data to keep only the matched households in the panel sample. Then, I use this new data set to estimate equation (6). I find that the solar units statistically increase the household income by 6.94% (see Table 1.8).

Table 1.7: Propensity score reweighted regression

VARIABLES	Δlog real inc
ΔT	0.041***
	(0.0138)
Δrain	0.001
	(0.0008)
Δrainsq	-9.65e-08
	(3.73e-07)
ΔHHmem	0.163***
	(0.0129)
ΔAge18-60	0.032**
	(0.0130)
ΔElder	-0.041
	(0.0367)
ΔDisabled	-0.050
	(0.0411)
ΔAge3-5	-0.013
	(0.0136)
ΔAge6-11	-0.064**
	(0.0259)
ΔAge12-14	-0.051**
	(0.0244)
Constant	0.113***
	(0.0341)
Observations	10,666
R-squared	0.111

Note: Robust standard errors in parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 1.8: DD with propensity score matching

VARIABLES	log real inc
T	0.069**
	(0.0309)
Rain	-0.0001***
	(2.72e-06)
Rainsq	-5.37e-08***
	(9.24e-10)
HHmem	0.157***
	(0.0100)
Age18-60	0.013
	(0.0117)
Elder	-0.010
	(0.0149)
Disabled	-0.041
	(0.0300)
Age3-5	-0.020**
	(0.0086)
Age6-11	-0.044*
	(0.022)
Age12-14	-0.019
	(0.0239)
	10.840***
Constant	(0.0403)
Year Effect	Yes
Household Effect	Yes
Province-year Effect	Yes
Observations	21,548
R-squared	0.355

Note: Robust standard errors in parentheses, clustered at province level
*** p<0.01, ** p<0.05, * p<0.1

6. Sustainability of the solar home system

Even though the solar home system gives a positive impact on household income, many of the systems malfunctioned several years after installation. In summer 2011, I had an in-depth interview with the PEA officer who was in charge of this program and a member of a nonprofit organization that volunteers to repair the systems in Tak province. They stated that malfunction is the most important problem of the program, and more than 80% of the systems have already failed.

In 2007, the Faculty of Engineering and Architecture of Rajamangala University of Technology in Thailand asked 3,350 treated households in 24 provinces all over the country about the experiences and satisfaction level from using the solar home system. Faculty of Engineering and Architecture (2007) found that 90% of the sample does not know how to repair the systems properly when the system is broken. Moreover, 74% of the treated households have never been educated about maintenance. Based on the data of this survey, I found that 3.89% of the treated households had a problem with the battery, solar panel, or inverter during the first year after they received the system. The failure rate for systems surviving past the first year increases to 6.34% in the second year, and the failure rate for systems surviving past the second year is 10.54% in the third year. Thus, on average, the failure rate is about 7% per year.

7. Comparing costs and benefits of the program

The main result of this study indicates that solar unit increases the household income by 6.9%. In this section, I conduct a back-of-the-envelope calculation to compare the costs and benefits[8] of the program.

[8] In this study, I measure the benefits of the program by measuring the increase in household income only.

From the data, the mean of the control household (HH06) annual income equals 93,901.35 baht in 2005 and my preferred estimates imply a 6.9 percent increase in income. Thus, the solar electricity system increased household income by about 6,479.19 baht (93,901.35*0.069). Since the Thai government provided approximately 200,000 solar electricity systems, the total benefits of the program were 1.295 million baht per year[9]. Assume that this total benefit is steady over time, that the probability that the solar unit breaks in a given year is constant at 0.07, and that all the solar units will be broken after 2010 (a conservatively low estimate of lifetime). Then, the present value (in 2005) of the total benefits is

$$\mathrm{PV} = \sum_{t=0}^{t=5} \frac{1{,}295{,}838{,}000(1-0.07)^t}{(1+r_t)^t}$$

where r_t is the real interest rate in time *t*. I use the annual average of real overnight interbank rate as a proxy. The data of real interbank rates from 2006 to 2010 are from Bank of Thailand. Thus, the present value of the total benefits is 6 billion baht. The cost of each solar electricity systems is approximately 25,000 baht. Thus, the total costs of the program is about 5 billion baht. Thus, the net present value of the program is about 1 billion baht or $25 million[10]. Note that this calculation does not include the installation costs and maintenance costs of the systems. Moreover, I also ignore the tradeoff between income and leisure. Nevertheless, this result indicates that the effects of the program on household income are meaningful.

8. Conclusions

This paper examines the impact of solar power initiatives for rural electrification on economic development by studying the effect of the Solar Home System project that Thailand's

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[9] Assuming that all 200,000 solar units were installed in 2005.

[10] The exchange rate is 40.22 baht/$ in 2005.

government implemented during 2004-2006. I exploit variation in the year of the solar installations across households to identify the program's causal effects using household-level panel data, which allows me to control for household fixed effects, trends, and province-year effects.

Despite the fact that the solar home system generates a small service of electricity, this research found significant impacts on income from the solar units. Solar units increased average household incomes by 6.9%. The result is robust to other identification strategies such as lagged dependent variable, propensity score reweighting, and differences-in-differences with propensity score matching. Even with skepticism about the sustainability of the program, a simple back-of-the-envelope calculation suggests that the net present value of the program (if all the value is income) is about 1 billion baht. Thus, it is not an exaggeration to conclude that rural electrification brings development and improved living standards to rural areas.

APPENDIX

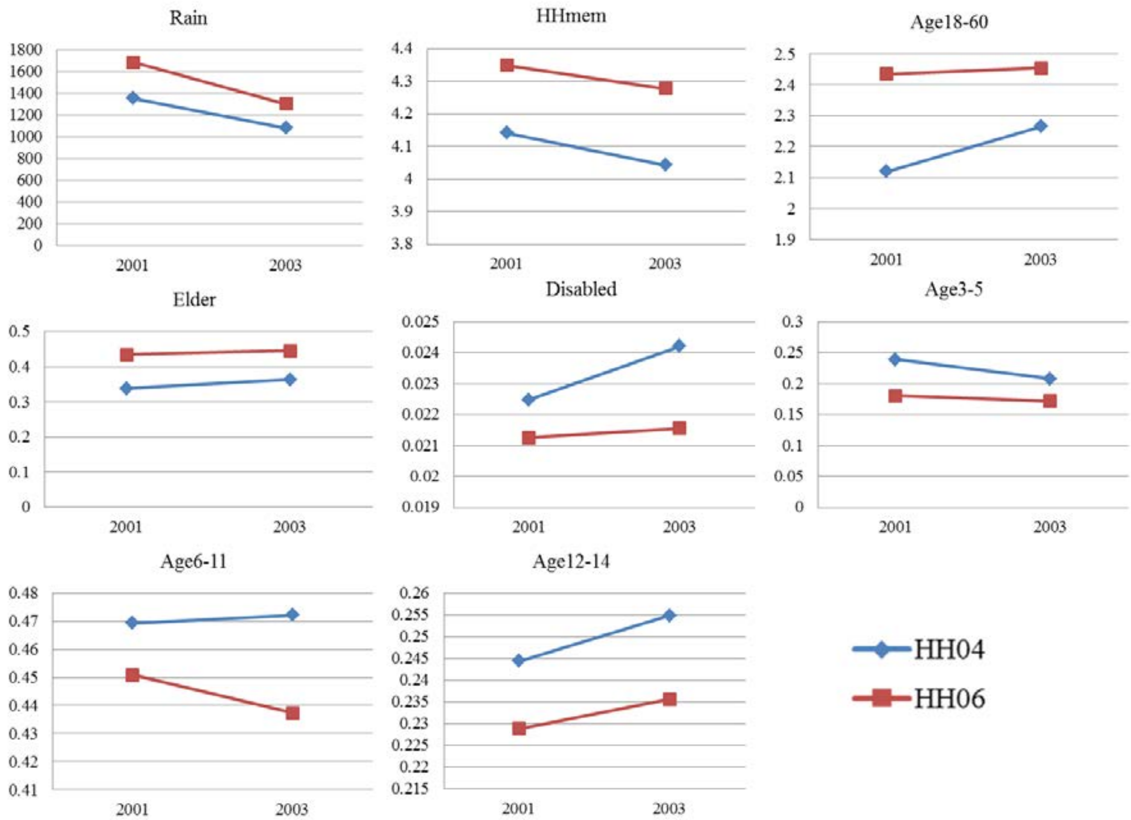

Figure A.1: Comparing pre-treatment trends of other variables between treatment and control groups

Table A.1: 2001-2005 data

VARIABLES	(1) log real inc	(2) log real inc	(3) log real inc	(4) log real inc
T	0.083	0.010		
	(0.0514)	(0.0359)		
T'			0.105*	0.017
			(0.0570)	(0.0332)
Rain	0.0002	4.78e-05***	0.0002	0.0001***
	(0.0002)	(2.31e-06)	(0.0002)	(2.38e-06)
rainsq	-4.54e-08	-1.35e-08***	-4.67e-08	-4.63e-08***
	(2.95e-08)	(5.19e-10)	(2.88e-08)	(3.69e-10)
HHmem	0.113***	0.111***	0.113***	0.111***
	(0.0125)	(0.0141)	(0.0125)	(0.0141)
Age18-60	0.053***	0.053***	0.053***	0.053***
	(0.0156)	(0.0138)	(0.0155)	(0.0137)
Elder	-0.007	0.010	-0.007	0.009
	(0.0189)	(0.0200)	(0.0190)	(0.0200)
Disabled	-0.057*	-0.054*	-0.056*	-0.054*
	(0.0325)	(0.0278)	(0.0324)	(0.0278)
Age3-5	-0.024	-0.012	-0.024	-0.012
	(0.0164)	(0.0137)	(0.0164)	(0.0136)
Age6-11	-0.025*	-0.024*	-0.025*	-0.024*
	(0.0131)	(0.0124)	(0.0130)	(0.0124)
Age12-14	-0.023**	-0.012	-0.023**	-0.012
	(0.0093)	(0.0118)	(0.0093)	(0.0118)
Constant	9.656***	9.984***	9.646***	9.972***
	(0.2740)	(0.0251)	(0.2680)	(0.0238)
Year Effect	Yes	Yes	Yes	Yes
Household Effect	Yes	Yes	Yes	Yes
Province-year Effect	No	Yes	No	Yes
Observations	50,374	50,374	50,374	50,374
R-squared	0.332	0.431	0.332	0.431

Note: Robust standard errors in parentheses, clustered at province level
*** p<0.01, ** p<0.05, * p<0.1

I employ data of 10,075 households that have the complete panel data set during 2001-2005 to estimate equation (6). Table A.1, columns (1) and (2) show that there is no significant impact on household income in this model specification. This might be due to the timing that solar unit was installed. Since the installations are distributed throughout the year, if households

Table A.1 (cont'd)

received their unit at the end of the year, annual income of that year will not reflect the impact of the solar unit. Moreover, households may take time to reschedule household activities from the daytime to nighttime in response to lighting. Thus, I allow treatment households to adjust their working behavior for at least 1 month by defining the treatment policy dummy (T') equals to 1 if the household owns the solar unit at least 1 month in year *t*. I find that the solar units statistically increase the household income by 10.5% when the province-year effect is not included (See column (3) of the table).

Table B.1: Estimation of propensity score

VARIABLES	TT
HHmem	0.060***
	(0.0173)
Elder	-0.076*
	(0.0409)
Disabled	0.007
	(0.158)
Age3-5	0.023
	(0.0583)
Age6-11	0.049
	(0.0388)
Age12-14	0.031
	(0.0534)
Constant	1.670***
	(0.1030)
Province Effect	Yes
Observations	11,053
Pseudo R-squared	0.245

Note: Standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

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CHAPTER 2

The Effects of Subsidies on Small-Scale Renewable Electricity Generation in Thailand

1. Introduction

The growing concern about climate change in the 1990s, policymakers around the world have been enthusiastically supporting a wide range of incentive mechanisms for renewable energy use, including in the electric power sector. Renewable energy is also supported to stimulate economies, enhance energy security, and diversify energy supply. As of early 2013, the Renewable Energy Policy Network for the 21st Century (REN21) reported that renewable energy support policies were implemented in 127 countries, more than two-thirds of which were developing countries or emerging economies (REN21 2013). While these renewable energy support policies are popular, less attention has been paid to how well the supporting policies work.

This paper analyzes the effects of a production subsidy targeting small-scale electric power producers in Thailand. In 2007, the Thai government introduced a technology-specific subsidy program for electricity producers with less than 10 MW of capacity. The program gives a subsidy for renewable energy generators on top of the normal prices that electricity producers would receive when selling electricity to the power utilities. For example, the subsidy is 0.30 baht[11] per kilowatt-hour (kWh) of energy produced using biomass, 3.5 baht per kWh of wind power, and 8 baht per kWh produced through solar energy. The subsidy was adjusted in 2009 to favor a relatively small power plant. For example, the production subsidy for electricity generators using biomass or biogas that have less than 1MW of capacity is 0.50 baht per kWh, while the subsidy for generators using biomass or biogas that have over 1MW of capacity is 0.30

[11] 1 baht is approximately 0.03 U.S. dollars in 2007.

baht per kWh. Thus, a biomass or biogas electricity producer generating at capacity of 1MW would earn a subsidy of 500 baht per MWh (approximately 1,350,000 baht or $40,500 per year, assuming the plant runs at 75% capacity for 10 hours per day), while a producer of infinitesimally higher capacity would earn a subsidy of just 300 baht per MWh (about 810,000 baht or $24,300 per year).

Since the total production subsidy in 2009 is a step function with a large "notch" at 1MW based on the power plant's capacity, power producers who plan to build a plant near 1 MW will have an incentive to respond strategically by building a plant on the side of the notch with a higher subsidy[12]. I develop a structural model of bunching to understand the linkage between subsidy policy and power plant producers' behavior. Then, I use a test developed my McCrary (2008) to examine the distribution of power plant size for electricity producers subject to the subsidy rate in 2009. I find the evidence of bunching around the notch. A falsification test shows that similar bunching does not exist in the distribution of plant size built before the introduction of the notched subsidy payment. Thus, power producers respond to the subsidy strategically, leading to bunching in the distribution of power plant size below the notch. The subsidy is intended to increase total electricity produced, but the notch structure gives producers an incentive to build a small power plant in order to receive a higher subsidy, thereby potentially reducing capacity. In addition, bunching implies variation in the long-run variable cost of generating electricity at notch, and therefore allocative inefficiencies in production.

While an existing literature studies the effect of subsidies on renewable energy production (Astranda and Neijb 2006; Carley 2009; Dong 2012; Lipp 2007; Palmer et al. 2011;

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[12] This is not a "tiered" tariff scheme in which a producer would earn the high price on the first units of production and then a lower price on subsequent units of production. Rather, if a producer's capacity is "epsilon" above the threshold, then it earns the lower price on *all* production.

Palmer and Burtraw 2005; Rio Gonzalez 2008; Haito and Powers 2010), few provide a structural model to explain the linkage between the subsidy policy on producer behavior. This paper fills the gap by developing a model to explain that mechanism.

Although subsidy policies encourage electricity producers to invest in renewable energy, the step function (notch) character of this policy may discourage them from investing in a large-scale generator, introducing economic distortions. While the notched subsidy scheme affects a large number of small-scale power producers, it does not affect a large quantity of installed capacity (since the producers are by definition very small). However, the Thai government recently began considering a new subsidy policy to initiate more electricity from renewable energy. They plan to increase amount of renewable energy from 10% of total electricity generation in 2012 to 20% in 2021 (Ministry of Energy, Thailand). Thus, the lessons learned from the small-scale subsidy program in this paper could help inform the expansion to larger producers, for which the potential welfare consequences could be quite large.

The rest of the paper is organized as follows. Next section discusses Thailand's very small-scale electric power producers program and subsidies policy. Then a simple model for bunching is introduced in section 3. Section 4 describes the data availability. Section 5 presents the reduced-form test for bunching and estimation results. Section 6 concludes with a summary of major findings.

2. Thailand's very small-scale electric power producers program and subsidies policy

In 2002, the Thai government began allowing very small power producers (VSPPs) with a maximum of 1 MW capacity that generated electricity from renewable energy sources[13] or cogeneration[14] to connect to the grid and sell excess electricity to the country's two power distribution utilities, i.e. the Provincial Electricity Authority (PEA) and the Metropolitan Electricity Authority (MEA). The objectives of this program are to reduce electricity generation using commercial fuels, to decrease expenditures on fuel imports from foreign countries, to distribute power generation to remote areas, and encourage public participation in the power generation, and to decrease the environmental impacts (Piyasvasti Amranand, Thailand's energy minister). Later, in 2006, the government raised the maximum purchase capacity from each VSPP from 1 MW to 10 MW.

To induce more power plants to produce electricity from renewable energy, in February 2007, the government began providing a subsidy on top of the normal prices that power producers receive when selling electricity to the Power Utilities. The amounts of the subsidies vary depending on the energy sources used. These subsidies will be provided for 7 years.

On 19 August 2009, the government adjusted the subsidy rates and the duration of the subsidy provision to encourage more investment in the VSPPs sector. For example, the subsidy for electricity producers using biomass or biogas with less than 1MW of capacity is 0.50 baht per kWh, while the subsidy for electricity producers using biomass or biogas with a capacity of 1MW or greater is 0.30 baht per kWh. To alleviate the investment risks for power generation

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[13] The renewable energy sources under VSPP regulations include power plants using wind, solar, hydro, wastes, biogas, and biomass.

[14] Cogeneration, or combined heat and power, uses waste heat or by-product heat from industrial production or electricity generation to produce electricity.

from renewable energy in the three southernmost provinces (i.e., Yala, Pattani and Narathivath)[15], the government gave the special subsidy rates to VSPPs located in these three provinces[16] (see Table 2.1). In order to qualify for the new subsidy rates, VSPPs must submit their proposal to sell electricity to PEA or MEA on or after Aug 19, 2009.

The subsidy policy in 2009 creates a notch in the total production subsidy for electricity producers using biomass, biogas, and wind energy. To illustrate, assume that a biomass power plant produces electricity at capacity for 4,000 hours per year. If the producer chooses to build the power plant at a size of 1 MW, he will receive a subsidy of 2 million baht per year[17]. However, if he chooses to build the power plant just bigger than 1 MW, say 1.01 MW, he will receive a subsidy of around 1.2 million baht per year[18]. Figure 2.1 shows the total production subsidy as a function of capacity based on this example, with a large “notch” at 1 MW.

In order to prevent fraudulent reporting of size to gain the subsidy, the PEA’s and MEA’s authority officers will cross-check the power plant to confirm its size. Also, an electricity meter will be installed to measure the amount of electric energy produced by each plant.

Presently, in June 2014, there are 460 VSPPs registered, which have total capacity equal to 1,621MW—an increase from only 3 VSPPs in 2003 which had 0.06 MW total capacity (see Figure 2.2). Table 2.1 shows the distribution of VSPPs by energy source. About 56% of VSPPs use solar power as a source of energy and produce half of total capacity. It is noteworthy that more than 90% of VSPPs generate electricity using solar power, biomass, and biogas.

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15 In the last decade, these areas have been faced several terrorism incidents.

16 Unfortunately, there is only one VSPP operating in these three provinces.

17 1 MW*0.5 baht per kWh *4,000 hours per year.

18 1.01 MW*0.3 baht per kWh *4,000 hours per year.

Table 2.1: The subsidy rates for VSPPs program

Energy sources & capacity	Subsidies in 2007 (Baht/kWh)	New subsidies (Aug 2009) (Baht/kWh)	Special subsidies for 3 Southern provinces (Baht/kWh)	Duration (years)
Biomass ≤ 1MW	0.30	**0.50**	1.00	7
Biomass >1 MW	0.30	0.30	1.00	7
Biogas ≤ 1MW	0.30	**0.50**	1.00	7
Biogas > 1MW	0.30	0.30	1.00	7
Wastes-Landfill/ anaerobic digestion	2.50	2.50	1.00	7
Wastes-Thermal Process	2.50	**3.50**	1.00	7
Wind ≤ 50 kW	3.50	**4.50**	1.50	10
Wind > 50 kW	3.50	3.50	1.50	10
Hydro 50 - 200 kW	0.40	**0.80**	1.00	7
Hydro < 50 kW	0.80	**1.50**	1.00	7
Solar	8.00	8.00	1.50	10

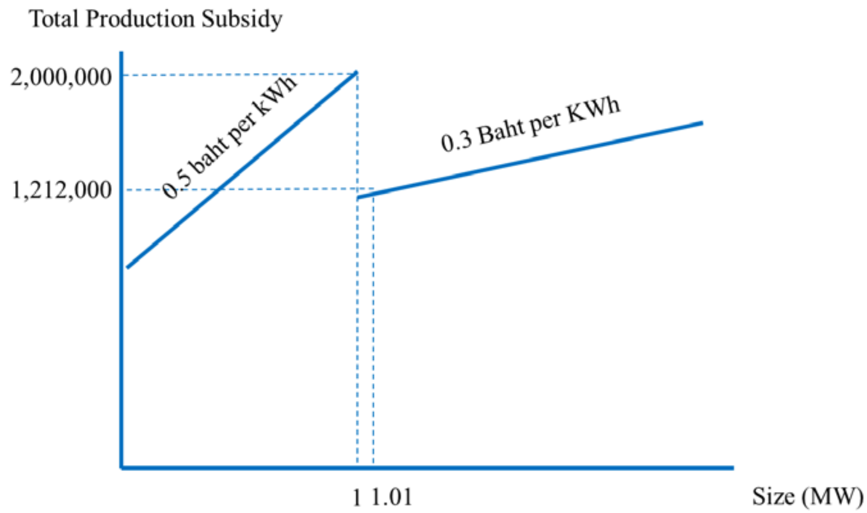

Figure 2.1: Total production subsidy as a function of capacity

Note: The subsidy policy in 2009 creates a notch in the total production subsidy for electricity producers using biomass and biogas. The subsidy for electricity producers using biomass or biogas with less than 1MW of capacity is 0.50 baht per kWh, while the subsidy for electricity producers using biomass or biogas with a capacity of 1MW or greater is 0.30 baht per kWh. If the producer produces electricity at capacity for 4,000 hours a year, the total subsidy

Figure 2.1 (cont'd)

for a 1 MW power plant is 2 million baht per year, while the total subsidy for a slightly larger power plant, say 1.01 MW, is about 1.2 million baht per year.

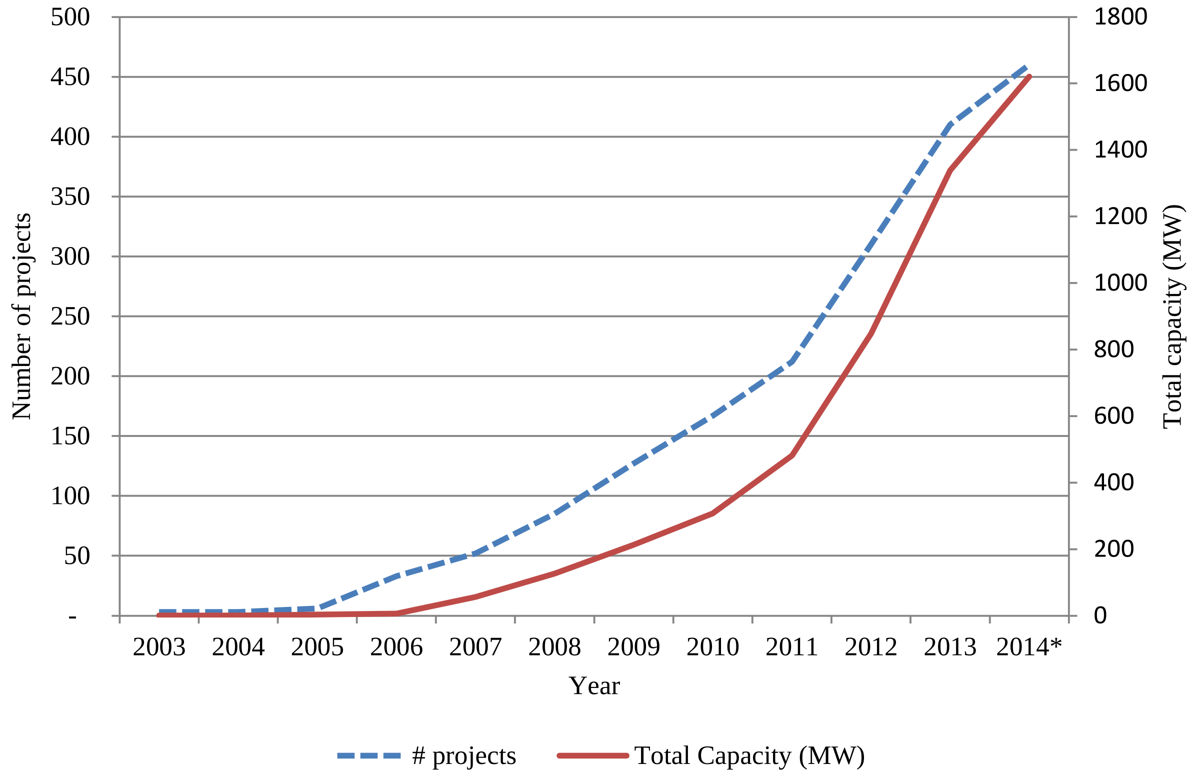

Figure 2.2: Number of VSPPs and total annual capacity (in MW) for VSPPs 2003-2014*

Note: * The 2014 data include through June 2014.

Table 2.2: The distribution of VSPPs by energy source in June 2014

Energy Sources	Projects		Capacity (MW)	
	#	Percent	#	Percent
Biomass	70	15.22	501.41	30.94
Biogas	101	21.96	214.87	13.26
Hydro	6	1.30	1.13	0.07
Solar	256	55.65	828.52	51.12
Wind	5	1.09	8.78	0.54
Cogeneration	2	0.43	13.60	0.84
Wastes-Landfill digestion	15	3.26	32.75	2.02
Wastes-Thermal process	5	1.09	19.60	1.21
Total	460	100	1621	100

3. A structural model of bunching

Since the total subsidy[19] for biomass and biogas generation in 2009 is a step function (notch) at 1MW of capacity, the power producers who plan to build a plant near 1 MW will strategically build a plant at the incentive-preferred side of notch. The simple explanation for bunching is modeled as follows.

Suppose that a potential renewable electricity producer (i.e., with access to renewable energy supply) maximizes his/her long run profits by choosing size of the power plant. For simplicity, assume that the producer plans to generate electricity at capacity. Let the long run variable costs C_i with respect to size S be given by $C_i(S_i) = e^{\alpha+\beta S_i+\varepsilon_i}$, where α is the variable cost for an average plant ($\varepsilon_i = 0$) with $S_i = 0$, β is percentage rate at which variable cost increases with size, and ε_i is an unobserved producer-specific cost shifter, such as the ability of the producer or the cost and availability of local renewable energy sources. Assume for

[19] It is important to note that the total subsidy payment is notched, not just the marginal subsidy.

illustrative purposes that ε_i has a normal distribution with mean 0 and standard deviation σ. The variable revenue with respect to the size of the power plant is $P(S_i)$ is given by:

$$P(S_i) = \begin{cases} P_{high} \text{ if } S_i \leq 1 \text{ MW} \\ P_{low} \text{ if } S_i > 1 \text{ MW} \end{cases}, \quad \text{where } P_{high} > P_{low}$$

Figure 2.3 shows the optimal size for power plant *i* for a range of possible values of ε_i. The optimal power plant size (S_i^*) can be described in 5 possible cases.

Case (I): The producer does not build the power plant, or $C_i(0) > P_{high}$ (see point A in Figure 2.3 for illustration). In this case, $\alpha + \varepsilon_i > ln\, P_{high}$. In other words, the cost of building the power plant is too high, even under the highest subsidy from the government. The probability that $S_i^* \leq 0$ equals

$$1 - \Phi\left(\frac{ln\, P_{high} - \alpha}{\sigma}\right),$$

where $\Phi(.)$ is the cumulative distribution function of ε_i.

Case (II): The marginal cost of power plant size equals P_{high} or $C_i(S_i^*) = P_{high}$ for $S_i^* \in (0,1)$. In this case, $\alpha + \beta S_i^* + \varepsilon_i = lnP_{high}$, or $S_i^* = \frac{lnP_{high} - \alpha - \varepsilon_i}{\beta}$. The producer will build a power plant size between 0 MW and 1 MW (see point B in Figure 2.3 for illustration). The probability that $0 < S_i^* < 1$ is

$$\Phi\left(\frac{lnP_{high} - \alpha}{\sigma}\right) - \Phi\left(\frac{lnP_{high} - \alpha - \beta}{\sigma}\right),$$

while the probability density function is

$$\emptyset\left(\frac{S_i^* - \left(\frac{lnP_{high} - \alpha}{\beta}\right)}{\frac{\sigma}{\beta}}\right) \text{ for } S_i^* \in (0,1),$$

where $\emptyset(.)$ is the probability density function of ε_i.

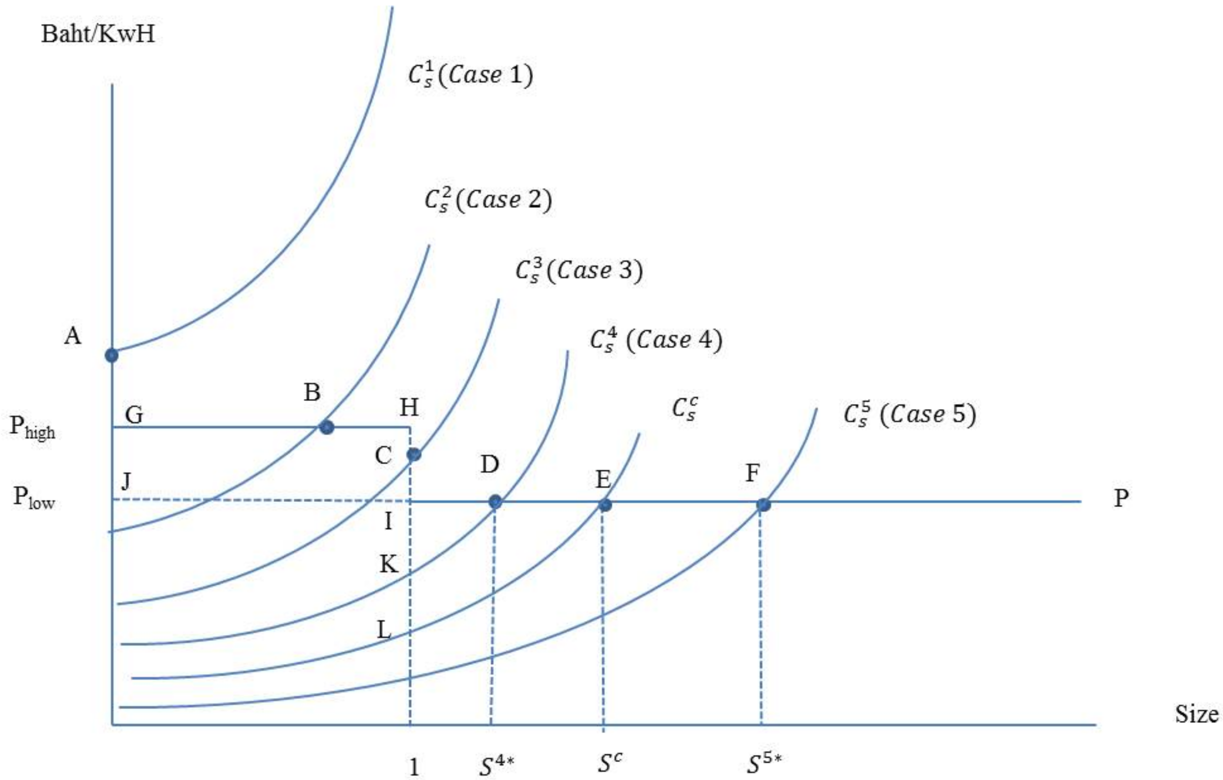

Figure 2.3: The optimal size for the power plants

Note: Let the long run variable costs C_i with respect to size S be given by $C_i(S_i) = e^{\alpha+\beta S_i+\varepsilon_i}$, where $\propto$ is a constant term, β is a scalar and ε_i is unobserved producer-specific cost shifter. The variable revenue with respect to size of the power plant is $P(S_i)$, which is given by

$$P(S_i) = \begin{cases} P_{high} \text{ if } S_i \leq 1 \text{ MW} \\ P_{low} \text{ if } S_i > 1 \text{ MW} \end{cases}, \quad \text{where } P_{high} > P_{low}.$$

Figure 2.3 shows the optimal size for power plant *i* for a range of possible values for ε_i. Consider producers that have C_s^4. Those producers will strategically change their plant size from their optimal size, S^{4*} , to 1 MW if the benefits from moving to the 1 MW notch (area GHIJ) is greater than the benefits from staying at S^{4*} (area IDK). This strategic behavior leads to the bunching in the distribution of the power plant size at the notch.

Case (III): The marginal cost of power plant size at $S = 1$ is located between P_{low} and P_{high} , or $P_{low} < C_i(1) < P_{high}$. In this case, $lnP_{low} < \alpha + \beta + \varepsilon_i < lnP_{high}$. The producer will build the power plant at size 1 MW (see point C in Figure 2.3 for example). The probability that $S_i^* = 1$ in this case is

$$\Phi\left(\frac{lnP_{high}-\alpha-\beta}{\sigma}\right) - \Phi\left(\frac{lnP_{low}-\alpha-\beta}{\sigma}\right).$$

Case (IV): The marginal cost of power plant size equals P_{low} , or $C_i(S_i^*) = P_{low}$ for $S_i^* \in (1, S^c]$[20], because the loss of the subsidy at the notch causes the producer to revert back to the notch. Suppose firm *i* chooses to build his/her plant size at $S_i^* > 1$ with $S_i^* = \frac{lnP_{low}-\alpha-\varepsilon_i}{\beta}$.

Then its profit is

$$\pi_i^*(\varepsilon_i;\ S_i^* > 1) = \left[\frac{lnP_{low}-\alpha-\varepsilon_i}{\beta}\right]. P_{low} - \frac{P_{low}}{\beta}.$$

Suppose instead that a firm chooses to build at $S_i = 1$. Then its profit is

$$\pi_i(\varepsilon_i;\ S_i = 1) = P_{high} - \frac{e^{\alpha+\beta+\varepsilon_i}}{\beta}.$$

There is a critical value of ε_i, ε^c, above which firms bunch at $S_i = 1$ and below which firms optimally choose $S_i^* > 1$. Note that this ε^c cannot be solved analytically. However, it can be solved numerically by equating $\pi_i^*(\varepsilon_i;\ S_i^* > 1) = \pi_i(\varepsilon_i;\ S_i = 1)$ (see Figure 2.4 for illustration). There is a unique critical value of size, S^c associated with this ε^c:

$$S^c = \frac{lnP_{low} - \alpha - \varepsilon^c}{\beta}$$

[20] S_i^c is the critical power plant size that make power producers indifferent between moving back to the 1 MW notch, or staying at their optimal size.

Thus, in this case, $\alpha + \beta + \varepsilon_i < lnP_{low}$ and $P_{high} - \frac{e^{\alpha+\beta+\varepsilon_i}}{\beta} > \left[\frac{lnP_{low}-\alpha-\varepsilon_i}{\beta}\right].P_{low} - \frac{P_{low}}{\beta}$, or the benefit from moving to the 1 MW notch (area GHIJ in Figure 2.3) is greater than the benefit from staying at S_i^* (area IDK if the optimal size of the producer is S^{4*}). The probability that $1 < S_i^* \leq S^c$ in this case is

$$\Phi\left(\frac{lnP_{low}-\alpha-\beta}{\sigma}\right) - \Phi\left(\frac{\varepsilon^c}{\sigma}\right).$$

This strategic behavior leads to further bunching in the density distribution of the power plant size at the notch. Combined with case III, the cumulative probability of bunching at the 1 MW notch is

$$\Phi\left(\frac{lnP_{high}-\alpha-\beta}{\sigma}\right) - \Phi\left(\frac{\varepsilon^c}{\sigma}\right).$$

Case (V) the marginal cost of power plant size equals P_{low}, or $P_{low} = C_i(S_i^*)$ for $S \in (S^C, 10)$. In this case, $\alpha + \beta S_i^* + \varepsilon_i = lnP_{low}$ or $S_i^* = \frac{lnP_{low}-\alpha-\varepsilon_i}{\beta}$ and $P_{high} - \frac{e^{\alpha+\beta+\varepsilon_i}}{\beta} < \left[\frac{lnP_{low}-\alpha-\varepsilon_i}{\beta}\right].P_{low} - \frac{P_{low}}{\beta}$. Power plant producers do not have any incentive to move from their S_i^* since the benefit from moving to the 1 MW, now, is less than the benefit from staying at S_i^* (see point F in Figure 2.3 for illustration). The probability that $S_i^c < S_i^* < 10$ equals

$$\Phi\left[\frac{\varepsilon^c}{\sigma}\right] - \Phi\left(\frac{lnP_{low}-\alpha-10\beta}{\sigma}\right),$$

while the probability density function is

$$\emptyset\left(\frac{S_i^* - \left(\frac{lnP_{low}-\alpha}{\beta}\right)}{\frac{\sigma}{\beta}}\right) \text{ for } S_i^* \in (S_i^c, 10)$$

Suppose that α, β, and the distribution of ε_i are the same before and after the notched policy is introduced. Panels A and C of Figure 2.5 show the relationship between the unobserved producer-specific cost shifter (ε_i) and optimal power plant size (S_i^*), and the distribution of S_i^*

both before and after the notched policy, respectively. Panel B shows the distribution of ε_i, which has a normal distribution with mean 0 and standard deviation σ.

Panel A illustrates the relationship between ε_i and S_i^*. Before the notched policy, every power producer received the same amount of subsidy, which is equal to P_{low}. The producers who have "high" marginal costs ($\alpha + \varepsilon_i > ln\, P_{low}$) will not build the power plant. In other words, the producers who have $\varepsilon_i > ln\, P_{low} - \alpha$ will have S_i^* =0. The producers who have $\varepsilon_i < ln\, P_{low} - \alpha$ will choose the size of their power plant according to the following equation: $S_i^* = \frac{lnP_{low} - \alpha - \varepsilon_i}{\beta}$. The relationship between ε_i and S_i^* before the notch policy is shown as a blue-dashed line with slope = $\frac{-1}{\beta}$.

After the notched policy is implemented, power producers who have power plant size less than 1 MW will get the subsidies equal to P_{high} per kWh of the electricity that they produce. The power producers who have a power plant size larger than 1 MW will get the subsidies equal to P_{low}, which is less than P_{high}. As described in cases (I)-(V) above, the relationship between ε_i and S_i^* after the notched policy is shown as a kinked red line. The producers who have $\varepsilon_i > ln\, P_{high} - \alpha$ will continue to have S_i^* =0. The producers who have $ln\, P_{high} - \alpha - \beta < \varepsilon_i < ln\, P_{high} - \alpha$ will continue to choose the size of their power plant according to the following equation: $S_i^* = \frac{lnP_{high} - \alpha - \varepsilon_i}{\beta}$. The producers who have $ln\, P_{high} - \alpha - \beta < \varepsilon_i < ln\, P_{low} - \alpha$, however, will bunch at 1 MW. In addition, producers who have $\varepsilon^c < \varepsilon_i < ln\, P_{low} - \alpha$ will strategically change their plant size from their optimal size to 1 MW (see case IV above for detail). The producers who have $\varepsilon_i < \varepsilon^c$ will continue to choose the size of their power plant according to the following equation: $S_i^* = \frac{lnP_{low} - \alpha - \varepsilon_i}{\beta}$.

If the number of the potential producers is normalized to 1, under the assumptions of the model, this study can conclude that the notched policy will induce the entry of new power producers $\Phi\left(\frac{lnP_{high}-\alpha}{\sigma}\right)-\Phi\left(\frac{lnP_{low}-\alpha}{\sigma}\right)$. A fraction $\Phi\left(\frac{lnP_{low}-\alpha}{\sigma}\right)-\Phi\left(\frac{lnP_{low}-\alpha-\beta}{\sigma}\right)$ of potential producers will increase their power plant sizes up to 1 MW. Some producers, fraction $\Phi\left(\frac{lnP_{low}-\alpha-\beta}{\sigma}\right)-\Phi\left(\frac{\varepsilon^c}{\sigma}\right)$, will decrease their power plant sizes to the 1 MW notch. The rest of the producers will not change their power plant sizes (see panel B for illustration).

Panel C depicts the effects of the change in the subsidy on the density of power plant size. Before the change in the subsidy, the density is smooth around the 1 MW notch (the blue-dashed density line). After the change in the subsidy, all power producers with ε between $lnP_{high}-\alpha-\beta$ and ε^c bunch at 1 MW, creating a spike in the density distribution (the red density line). So the density is no longer smooth at 1 MW. There also is a hole in the post-density distribution since producers do not want to build their power plants between 1 MW and S^c MW.

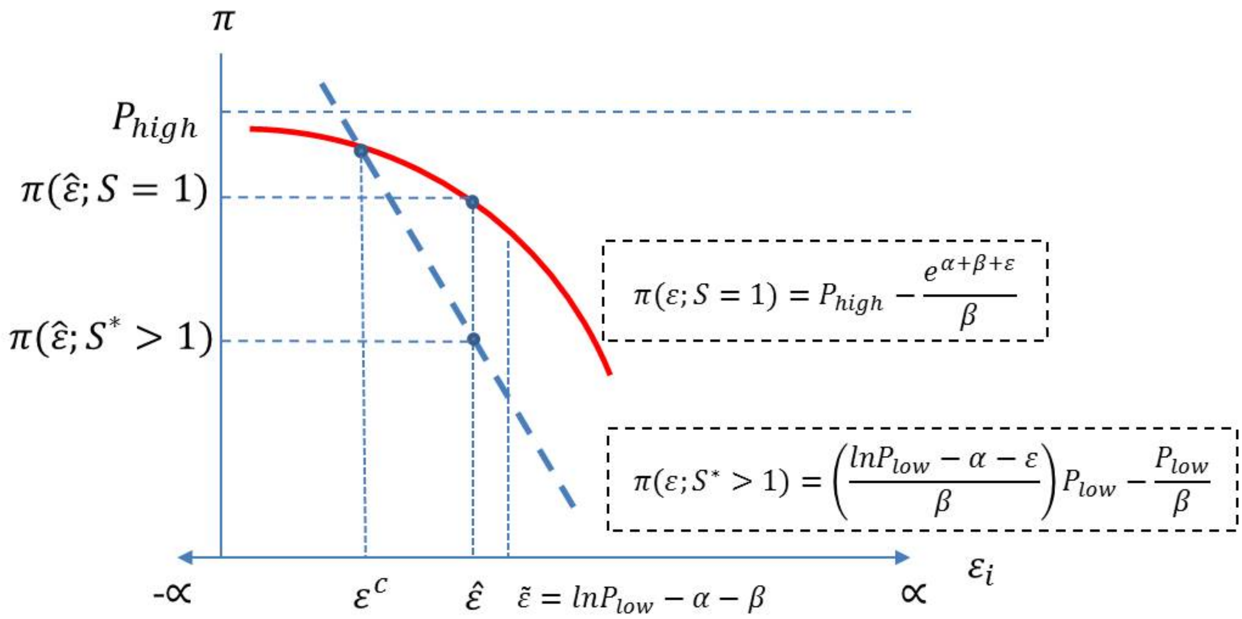

Figure 2.4: The unique $\boldsymbol{\varepsilon^c}$

Note: The concave red line shows $\pi_i(\varepsilon_i;\ S_i = 1) = P_{high} - \frac{e^{\alpha+\beta+\varepsilon_i}}{\beta}$. The linear dashed line is $\pi_i^*(\varepsilon_i;\ S_i^* > 1) = \left[\frac{lnP_{low}-\alpha-\varepsilon_i}{\beta}\right].P_{low} - \frac{P_{low}}{\beta}$. Let $\tilde{\varepsilon} = lnP_{low} - \alpha - \beta$ corresponds to $\tilde{S} = \frac{lnP_{low}-\alpha-\tilde{\varepsilon}}{\beta} = 1$. If a producer optimally chooses power plant size at $\hat{S} = \frac{lnP_{low}-\alpha-\hat{\varepsilon}}{\beta} > 1$ (note: $\hat{\varepsilon} < \tilde{\varepsilon}$), the profit at $\hat{S}$ or $\pi(\hat{\varepsilon}; S^* > 1)$ is less than the profit if the firm instead chooses to produce at $S_i = 1$ or $\pi(\hat{\varepsilon}; S = 1)$. Thus, as ε declines from $\tilde{\varepsilon}$, $\pi(\varepsilon; S = 1) > \pi(\varepsilon; S^* > 1)$ until ε reaches ε^c. If $\varepsilon < \varepsilon^c$, then it is optimal for firms to go above 1 MW.

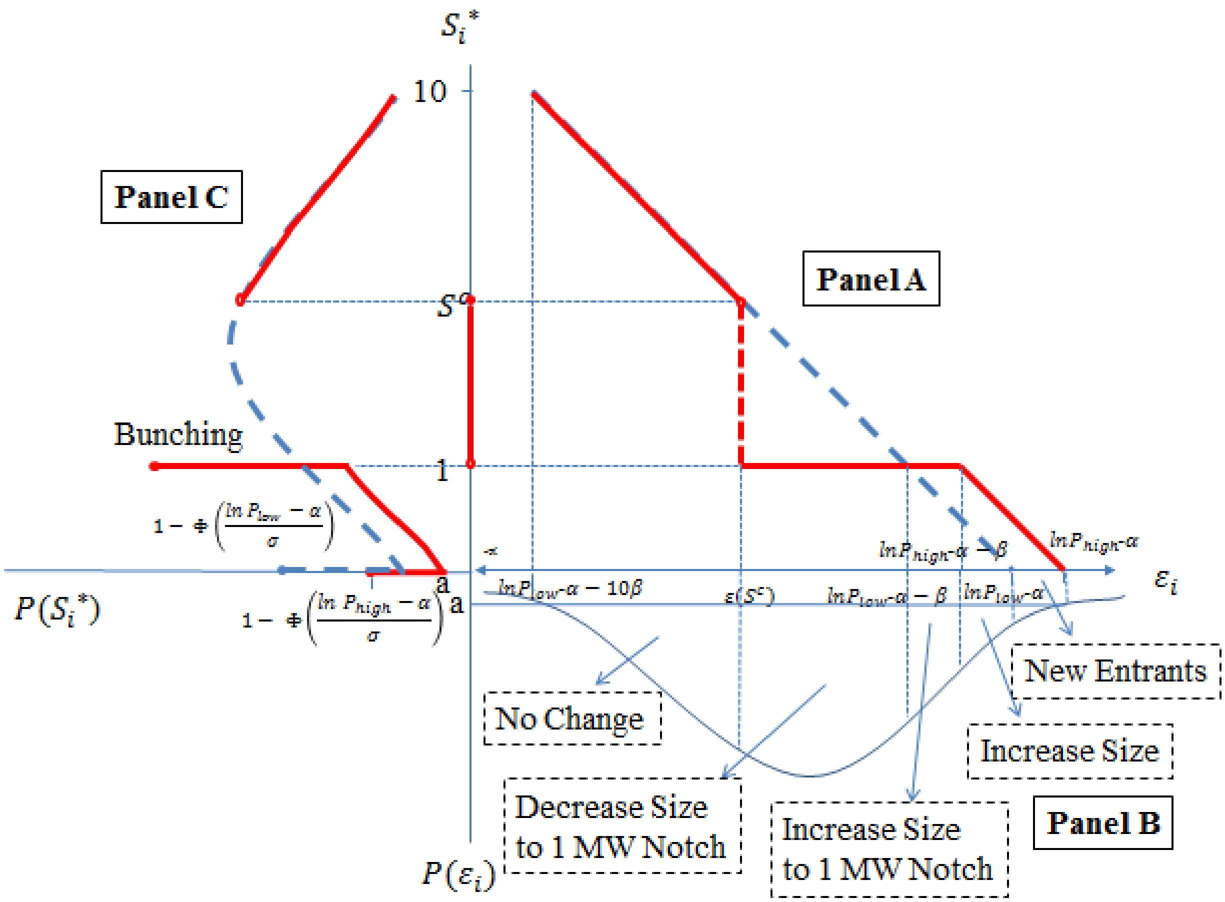

Figure 2.5: Behavior of power producers in response to a notch in the subsidy

Note: Panel A shows the relationship between the unobserved producer-specific cost shifter (ε_i) and optimal power plant size (S_i^*). The distribution of ε_i is shown in panel B. Panel C shows the density distribution of power plant size before and after notch policy. From panel A, the relationship between ε_i and S_i^* before the notch policy is shown as a blue dashed line with slope = $\frac{-1}{\beta}$, and the relationship between ε_i and S_i^* after the notch policy is shown as a kinked red line. From panel C, the blue dashed line shows the normal density distribution of the power plant size without the notch policy. The solid red line shows the bunching in the density at the notch, corresponding to the analysis in Figure 2.4 when the notch policy is implemented.

4. Data availability

This study focuses on the sizes of biomass and biogas power plants, since the subsidy for solar energy does not change during the period of study and since there is very little electricity generated from other renewable energy sources in Thailand (see Table 2.2). Thus, this study uses cross sectional data for 171 biomass and biogas power plants from the Energy Regulatory Commission in Thailand. The data include generator name (household, firm, or non-profit organization), address (province), types of fuel used, power plant capacity (MW), project approval date (D/M/Y), and start date for electricity sales (D/M/Y) of the power plants.

To improve precision of the density estimates in the next section, I combine the data above with the data for power plants that have applied to the subsidy program but have not yet delivered electricity. Some of these applications are still waiting for approval or are under construction, while others have cancelled their applications. This yields a bigger data set (634 power plants). I will call this data set the "big" data set and the earlier data set the "small" data set throughout the paper.

5. Reduced-form test for bunching

The subsidy for producers using biomass or biogas was adjusted in 2009 to favor a relatively small power plant. The subsidy rate is 0.50 Baht per kWh for a generator below 1MW capacity, and 0.30 Baht per kWh for a generator above 1MW capacity. As a result, the total subsidy for biomass and biogas in 2009 is a step function (notch) at 1MW. Thus, power producers who plan to build a plant near 1 MW will have a strong incentive to build a plant at the side of the notch with the larger subsidy.

The identifying assumption in bunching estimation is that the probability density function (pdf) of power plant size would be smooth at 1 MW in the absence of the notched subsidy. I use the data of power plants established before the change in the policy in August 2009 to verify that the bunching is in fact due to the notch in the subsidy function and not some other feature of renewable electricity technology or the economic environment. The difference in the distribution of power plants founded before and after August 2009 near the threshold provides strong evidence of bunching.

5.1 Graphical evidence

I employ the data of 171 existing power plants that use biomass and biogas as energy sources to draw the histogram before and after the change in the policy. Figure 2.6 presents histograms of power plant generating capacity. The dark-shaded histogram shows the distribution for plants built between August 2009 and June 2014 (post-policy), during which time the notch was present at 1MW. The light-shaded histogram shows the distribution for plants built before August 2009, before the introduction of the notched subsidy (pre-policy). The post-policy distribution shows a noticeable deviation from the pre-policy, distribution with a mass of observations at 1 MW. It is worth noting that there is no obvious gap in the density immediately above 1 MW, as shown in Figure 2.5 (Panel C). Some producers might face optimization frictions such as inattention and inertia (Kleven and Waseem 2013). The subsidy does appear, however, to have increased the mass of small producers, in part by shifting some of the mass above 1 MW backwards to the notch, which is expected. Figure B.1 and C.1 in appendix show the same information for narrower and wider bin sizes.

These histograms are based on a relatively small number of power producers, which can lead to considerable noise in the density estimates. To reduce this noise, I combined the data of the power plants that are already producing with the data of the plants that have applied to the subsidy program but have not yet started producing. Some of these plants are still in the waiting process, while some of them have cancelled their applications. Figure 2.7 shows the similar evidence of bunching at 1 MW. Figure D.1 and E.1 in appendix show the same information for narrower and wider bin sizes.

It is worth noting that there is also a bunching at 10 MW, which can be explained as follows. To gain the subsidy, electricity generators who have capacity between 10 MW-90 MW (small power producers, or SPPs) have to satisfy additional permitting requirements, including the provision of an environmental impact assessment. Also, the subsidy rate for such plants is determined by competitive bidding, with a maximum subsidy rate of 0.3 baht per kWh. Therefore, electricity producers who plan to build a power plant near 10 MW have a strategic incentive to be just below 10 MW, to receive a guaranteed of subsidy rate of 0.3 baht per kWh, and to avoid extra permitting requirements. However, the magnitude of bunching at 10 MW decreases in 2009 because the 0.3 baht per kWh was in the fact promised to all electricity generators who had capacity between 10 MW-90 MW. In any case, this study will be dedicated to the bunching at 1MW.

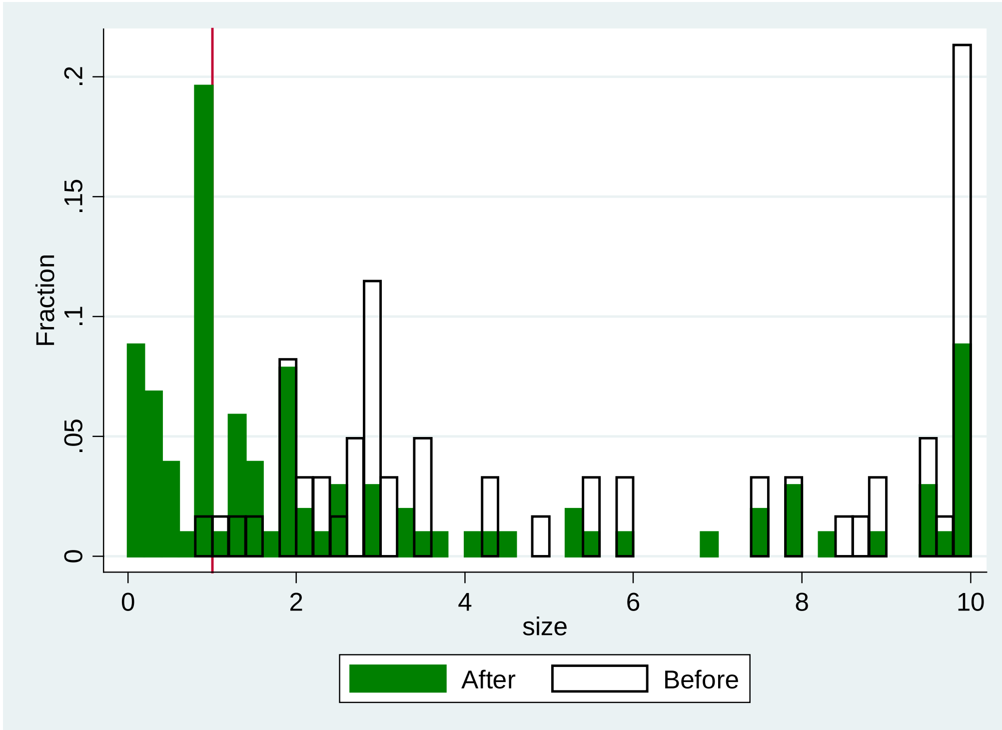

Figure 2.6: Evidence of bunching from the small data set (binsize = 0.02 MW)

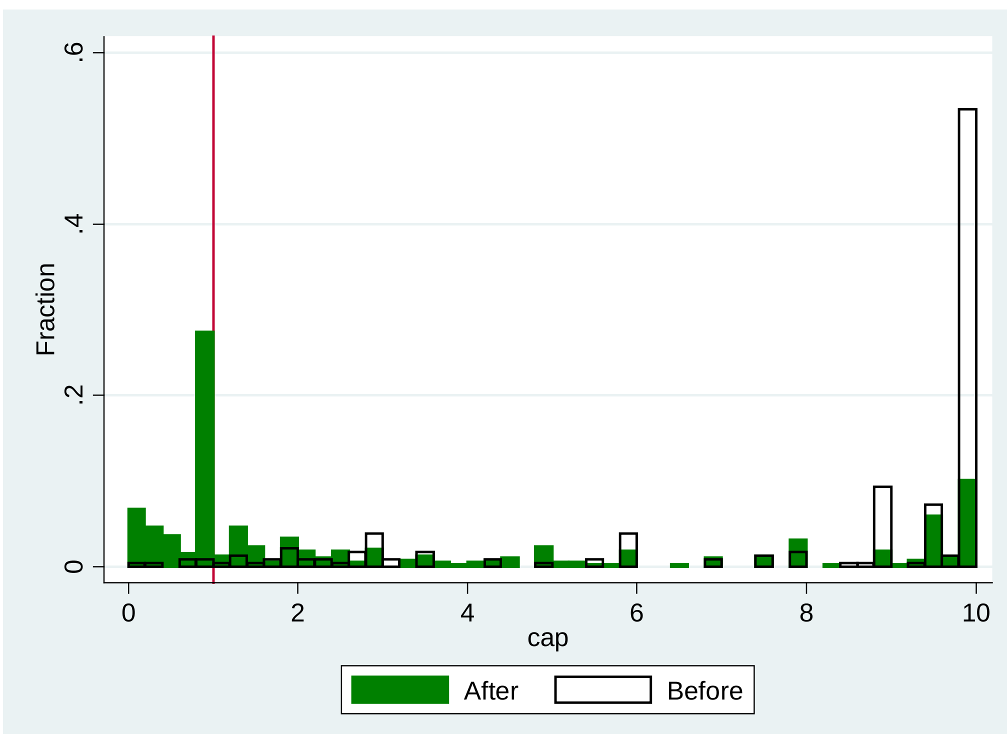

Figure 2.7: Evidence of bunching from the big data set (binsize = 0.02 MW)

5.2. A formal test for bunching

McCrary (2008) develops a formal test for bunching by estimating the discontinuity in the estimated density of a variable potentially subject to manipulation in response to a notched incentive.[21] The McCrary test has 2 steps. The first step is to create a histogram of the variable in which there is no bin overlapping the notch. For the second step, local linear regression with kernel-weighting is used to smooth the histogram on either side of the threshold and test for a discontinuity.

The test statistic for bunching is derived by taking the log difference in the height of the density of the running variable when the density is estimated separately with points to the left and to the right of the notch:

$$\hat{\theta} = ln\widehat{f^+} - ln\widehat{f^-},$$

where $\widehat{f^+}$ and $\widehat{f^-}$ are the estimated density function just above and just below the cutoff point, respectively. The null hypothesis is that $\hat{\theta} = 0$ at the notch, or that there is no bunching.

I use the data of power plants established after the change in the policy in August 2009 to perform a test of bunching. Figure 2.8 gives graphical results of the test. The figure strongly suggests that the density function of power plant size is discontinuous at the 1 MW notch. The estimated parameter $\hat{\theta}$ and its standard error are shown in Table 2.3. The t-test rejects the null hypothesis of continuity at the 95% significant level. The test indicates that the estimated density to the left of the notch is 2.3 times the estimated density to the right of the notch. As theory predicts, power producers strategically manipulate their power plant size to be at or just below

[21] The test was developed as a diagnostic for manipulation of the running variable in a regression discontinuity design. Used in this original context, evidence of bunching would imply that I cannot use the notch in the subsidy to identify intensive-margin responses of electricity supply to prices.

the notch to receive the higher subsidy. Unfortunately, the “small” data set is not rich enough to do a falsification test. Since there is no power plant with a size less than 1 MW before the change in policy in August 2009, the kernel-weighted linear regression on the left side of the threshold cannot be estimated.

Thus, I use the “big” data set to perform a bunching test. Figure 2.9 and 2.10 give an estimate of the density function of the power plant size after and before the change in policy in August 2009, respectively. Table 2.4 gives the results from the test for a discontinuity and indicates a significant discontinuity in the distribution of power plant size for the power plants founded after August 2009 (column 1). Moreover, column 2 shows that the null hypothesis of continuity cannot be rejected for the power plants established before August 2009.

These results are in line with previous findings. Saez (2010) and Kleven and Waseem (2013) observe large bunching in the distribution of income at kink points in the income tax schedule in the U.S. and Pakistan, respectively. Sallee and Slemrod (2012) find that the Gas Guzzler Tax creates bunching in the distribution of fuel economy ratings on the tax-preferred side of notches. They also show that welfare losses may occur when firms strategically exploit notched policies. Ito and Salee (2014) observe bunching in the distribution of vehicle weight in response to fuel economy targets in Japan, which are a step function (notches) of vehicle weight.

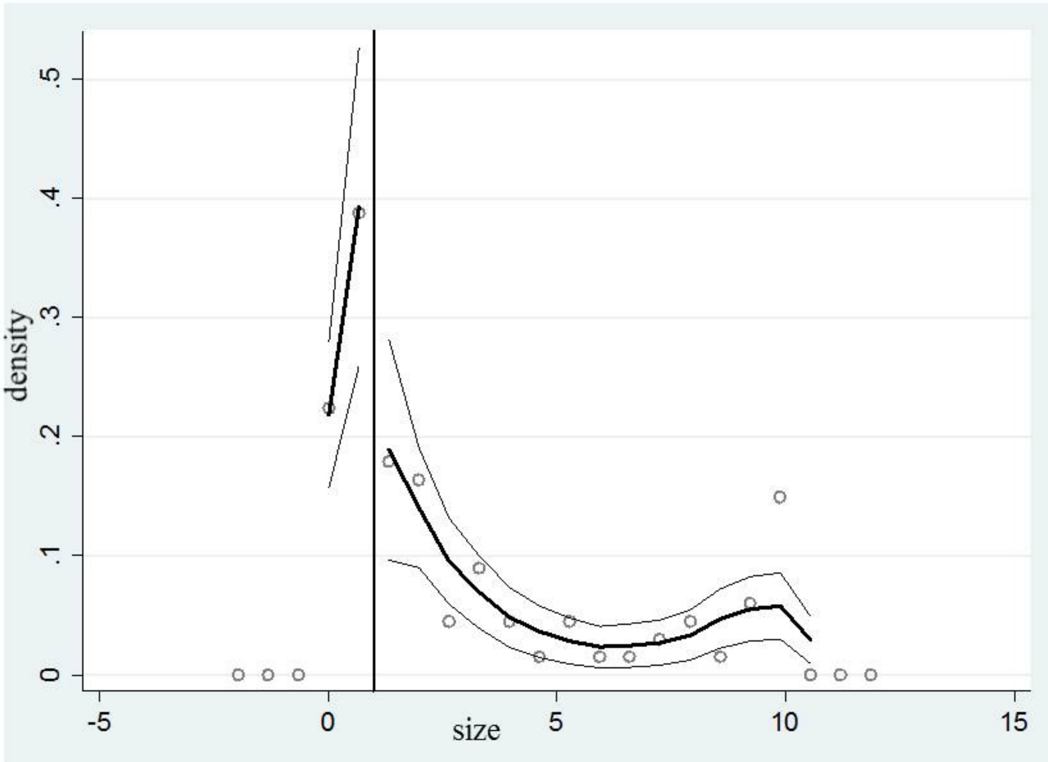

Figure 2.8: Test for bunching from the small data set

Note: Dashed line represents 95% confidence intervals. Circles represent undersmoothed histogram of data.

Table 2.3: Test for discontinuity in the estimated density of power plant size from the small data set

	After notch policy
difference in log density at notch	-0.8343*
Standard error	(0.4135)
Bandwidth	1.8836
N	102

Notes : 1) I used the bandwidth guided by an automatic procedure suggested by McCrary (2008).

2) Standard error is in parentheses.

3)*Significant at the 95% level.

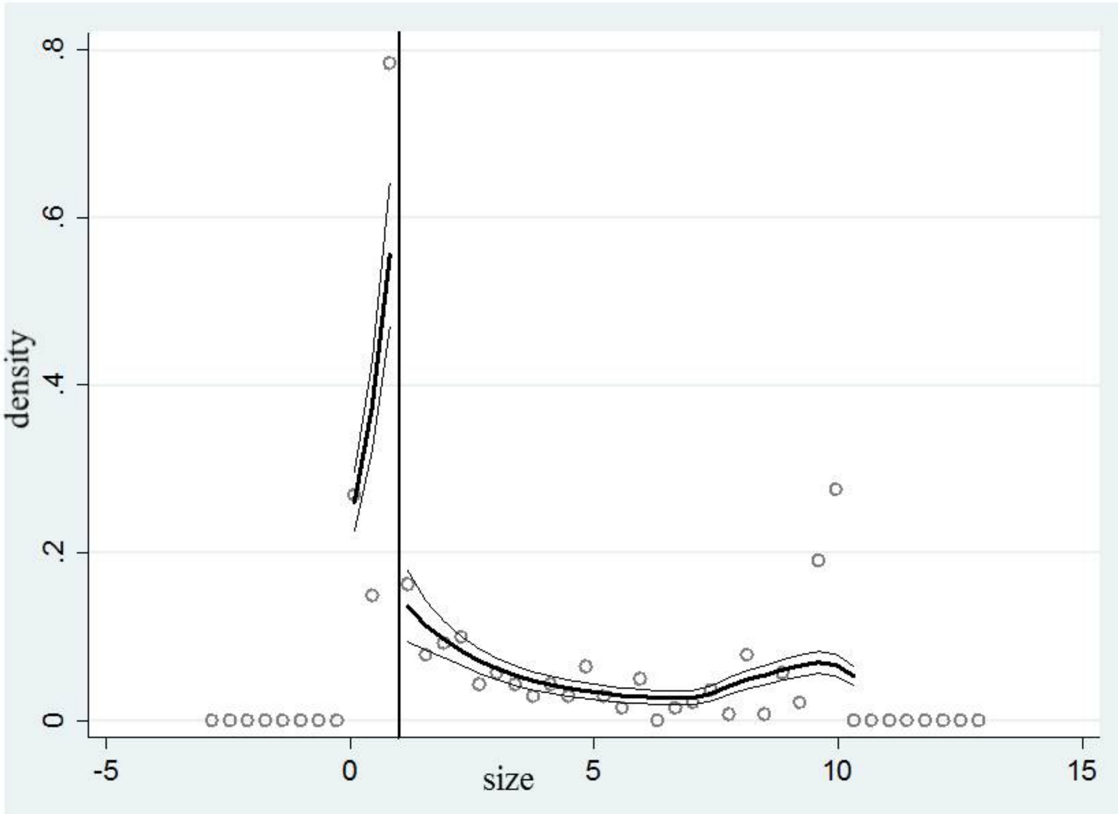

Figure 2.9: Test for bunching from the big data set

Note: Dashed line represents 95% confidence intervals. Circles represent undersmoothed histogram of data.

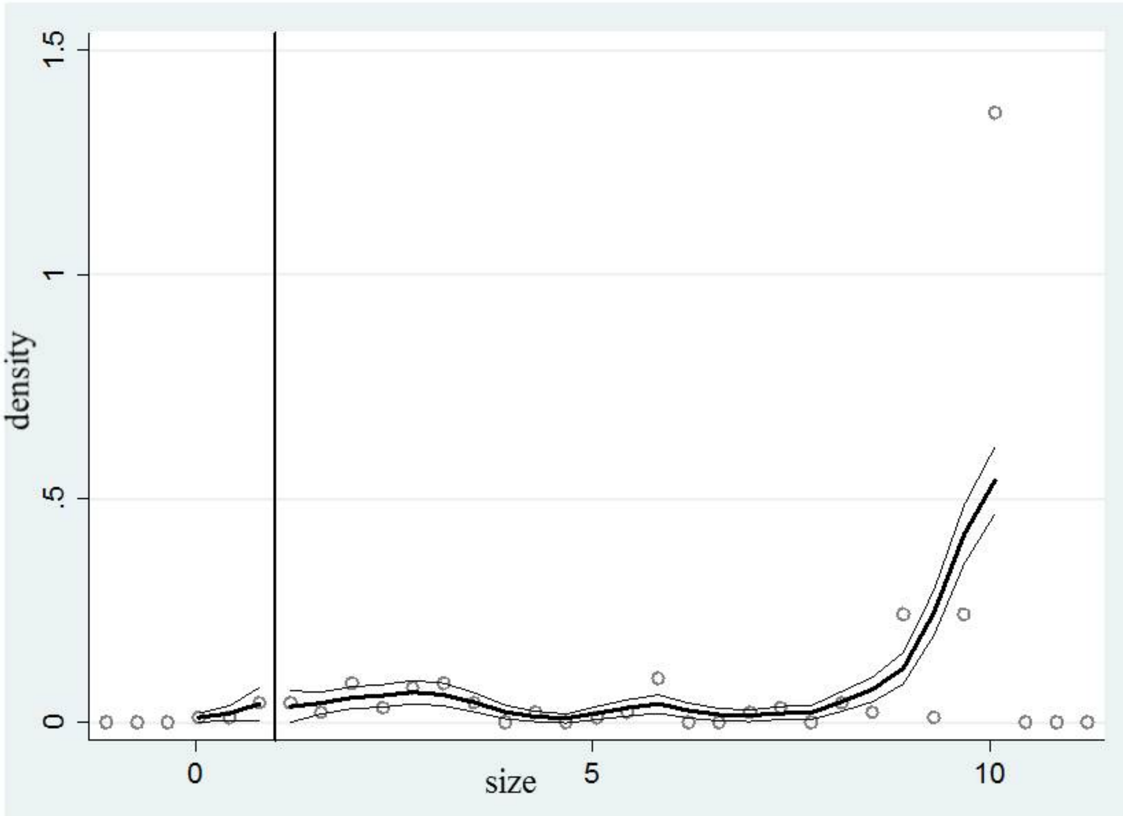

Figure 2.10: Falsification test for bunching from the big data set

Note: Dashed line represents 95% confidence intervals. Circles represent undersmoothed histogram of data.

Table 2.4: Tests for discontinuity in the estimated density of power plant size from the big data set

	After notch policy (1)	Before notch policy (2)
difference in log density at notch	-1.4849*	-0.3436
Standard error	(0.20099)	(0.9251)
Bandwidth	2.5752	1.0556
N	387	236

Notes : 1) I used the bandwidth guided by an automatic procedure suggested by McCrary (2008).

2) Standard error is in parentheses.

3)*Significant at the 95% level.

6. Conclusions

This paper examines the response of small-scale electric power producers to a notched subsidy policy. The Thai government gives a technology-specific subsidy for electricity producers with less than 10 MW capacity. The program gives a subsidy for renewable energy generators on top of the normal prices that electricity producers would receive when selling electricity to the power utilities. The total production subsidy in 2009 is a step function with a large “notch” at 1MW based on the power plant’s capacity. This notch provides an incentive for power producers who plan to build a plant near 1 MW to strategically build a plant on the side of the notch with a higher subsidy. I find evidence of bunching in the distribution of power plant size around the notch for the power plants subject to the subsidy rate in 2009. A falsification test shows that similar bunching does not exist in the distribution of plant size in 2006, before the introduction of the notched subsidy payment. I also use a test developed by McCrary (2008) to evaluate whether power producers alter their power plant size to avoid a discontinuous decrease in the subsidy. The McCrary test shows significant bunching, with a statistically significant discontinuity in the density of plant size that implies 2.3 times as many plants are just small enough to receive the subsidy than are just barely too big. Even though the subsidy is intended to increase total electricity produced by small producers, the notch structure creates a perverse incentive to build a small power plant in order to receive a higher subsidy.

APPENDIX

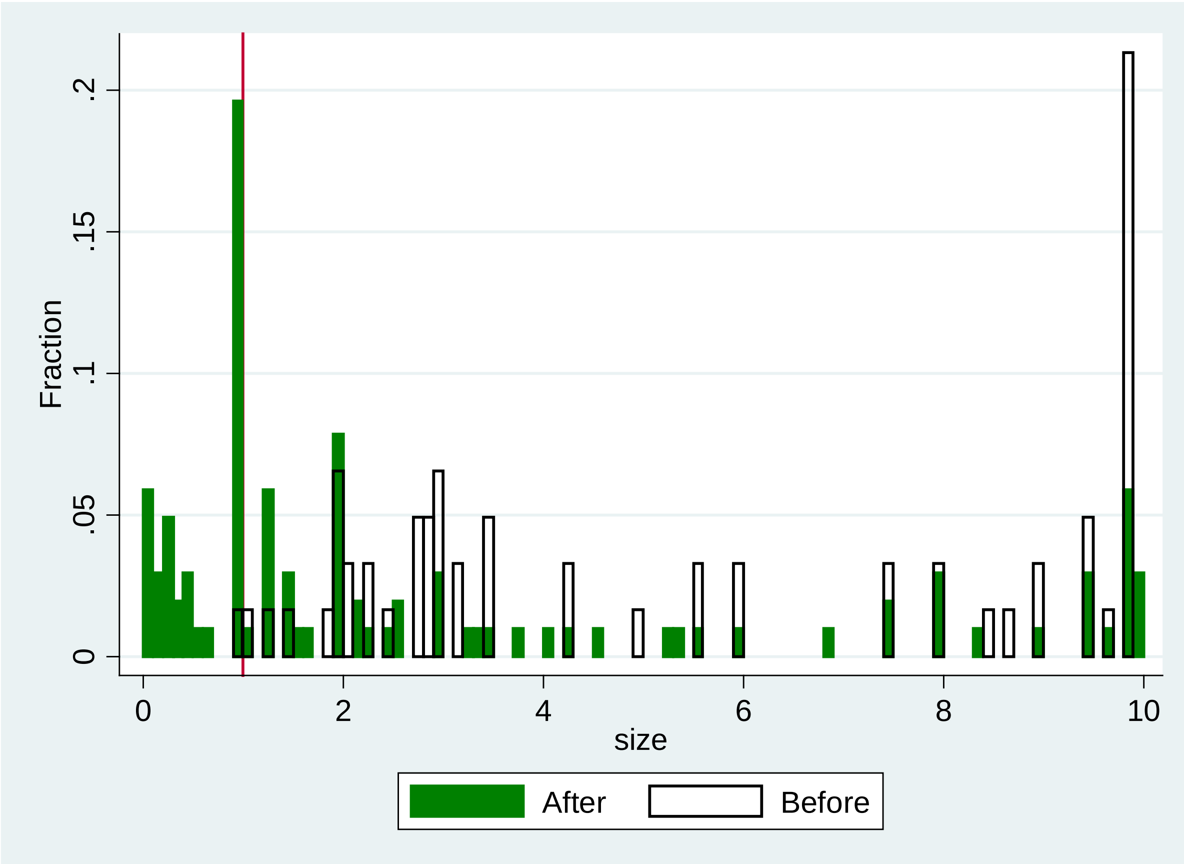

Figure B.1: Evidence of bunching from the small data set (binsize = 0.01 MW)

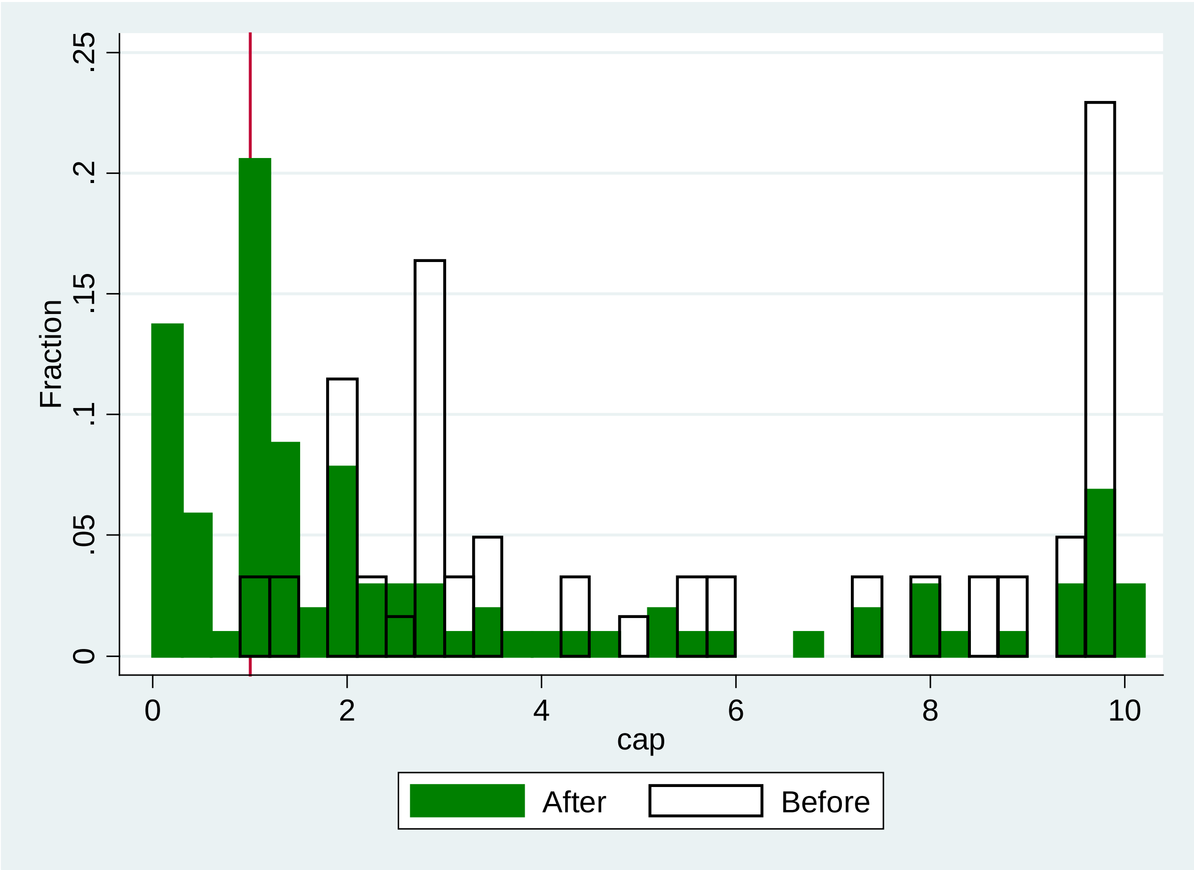

Figure C.1: Evidence of bunching from the small data set (binsize = 0.03 MW)

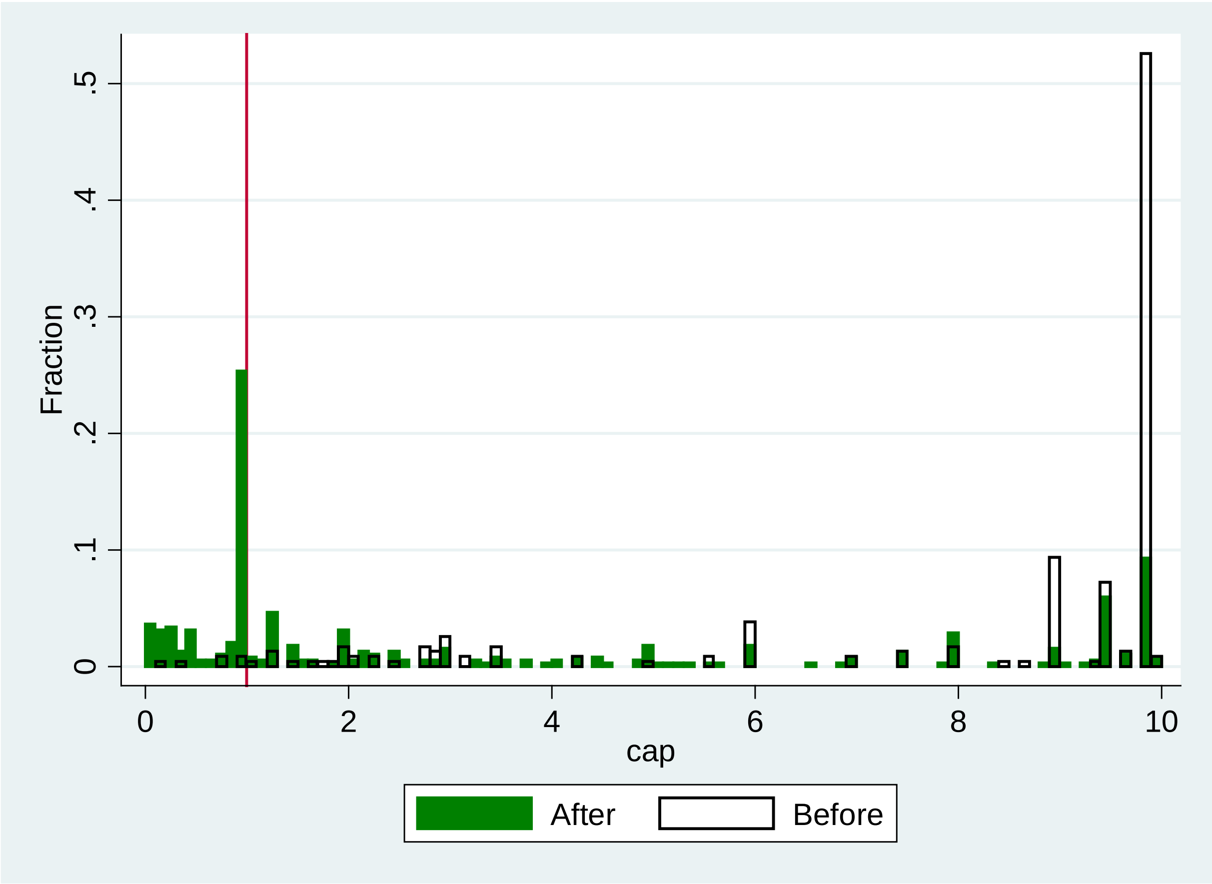

Figure D.1: Evidence of bunching from the big data set (binsize = 0.01 MW)

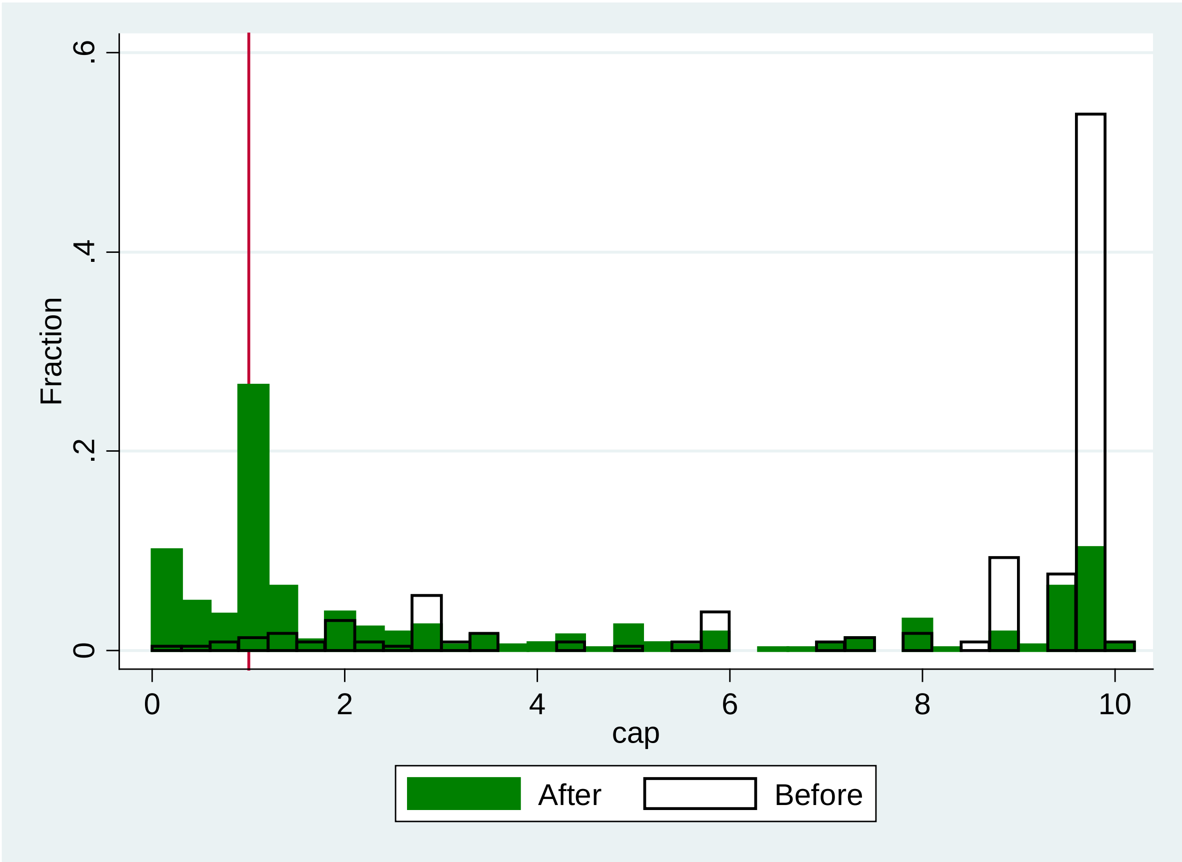

Figure E.1: Evidence of bunching from the big data set (binsize = 0.03 MW)

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CHAPTER 3

The Effects of the First-Car Buyer Excise Tax Rebate on Small Car Sales in Thailand

1. Introduction

The dramatic increase in gasoline prices around the world has encouraged the governments of many countries to focus on fuel efficiency policy. The government of Thailand is also compelled to impose a fuel efficiency policy since the price of gasoline in Thailand has more than doubled from 1998 to 2008[22]. In order to inspire consumers to consider a small engine car which consumes less fuel, the government introduced the eco-car policy into the market in October 2009. Under the eco-car program, the Finance Ministry offered to reduce the excise tax rate from 30% to 17% on cars that have small engine sizes and that are fuel efficient. Shortly after the policy was put in place, the first eligible eco-car was introduced to the automobile market at a price of 459,000 baht,[23] which is almost 20% lower than the next affordable car. Sales of eco-car models grew to 7,000 cars within six months and have continued to rise to 40,000 cars in August 2011.

In late 2011, the government launched a first-car buyer program in order to stimulate the growth of the automotive industry, which has become a large share of the Thai economy. Under the first-car buyer scheme, eligible first-time car buyers[24] will receive an excise tax deduction. The goal of the policy was to make it easier for low income buyers to purchase a vehicle and boost domestic automotive manufacturing. The goal of stimulating the economy through the growth of the automotive industry is employed by several governments around the world, e.g.

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[22] Price of Benzene 91 was increased from 12.42 baht per liter in January 1998 to 31.88 baht per liter in January 2008.

[23] 1 baht is approximately 0.03 U.S. dollars.

[24] See section 2.2 for detail.

the cash-for-clunkers program in the U.S. This idea appears to fit Thailand's economy because the number of people who own passenger vehicles in Thailand is relatively low[25]. There are great possibilities for growth in automotive industry.

Several studies have examined the effect of this kind of policy in the U.S. and developed countries (Li, Linn, and Spiller 2013; Mian and Sufi 2012; Kaul, Pfeifer, and Witte 2012; Nina and Frank 2013). However, the lessons learned from these studies might not be applicable to the case of developing countries, such as Thailand. Car in many developing countries is considered luxury goods, which has a higher price elasticity of demand than in the U.S. Therefore, in developing countries, a policy that lowers the price of a vehicle would have a larger impact on the demand.

The introduction of the new car buyer subsidy reduces costs of eco-car models, but by less than non-eco-car models. Thus, the first car buyer policy might create unintended effects on the eco-car project that the government also strongly promotes. On the one hand, since the first car buyer program was announced, potential eco-car buyers may have started to reconsider their choices, including cars with larger engines that are now eligible for a large tax reduction. Because eco-cars already have a lower excise tax than other vehicles, the new car buyer tax rebate is lower. A larger vehicle (1,400cc), such as Honda Jazz, Honda City, Toyota Vios, or Chevrolet Aveo, offer savings of 100,000 baht, while the eco-car offers savings of just 50,000-80,000 baht. On the other hand, the first car buyer program may also induce an increase in eco-car sales, since it allows a lower income household to buy a vehicle. A person who cannot afford, for example the Nissan March at 450,000 baht, is now able to purchase one for less than 400,000

[25] According to data from the World Bank, the number of passenger cars per 1,000 people in Thailand was 62 in 2009 and 67 in 2010 (compared to 439 and 426 respectively in the U.S.). Cars are relatively expensive in Thailand, with the country standing in 50th place out of 58 countries in the Economist Intelligence Unit's affordability rankings for compact cars (ranking by car price/ personal income).

baht. The theoretical effect of the program on eco-car sales is therefore ambiguous, making it an important empirical question. A systematic look at the data to understand the impact of the program is essential.

In this paper, I examine the effects of the first-car buyer program on the share of eligible cars and the share of eco-car sales using province-level data of monthly new vehicle registrations by vehicle model from 2007-2012. Due to the availability of the data, this study focuses on vehicle models less than 1,600cc, which accounts for 50% of all new personal vehicle registrations. The panel data set allows me to control for vehicle model and province-time fixed effects when examining the relationship between the program and share of vehicle sales. I find that the first-car buyer program significantly increases the sales share of eligible cars. I also find that the program decreases the share of eco-car sales, but not significantly.

While the program was national in scope, its impact on a given province might depend heterogeneously on the number of qualifying car buyers for the program. I take account of this issue by including a variable that measures exposure to the first-car buyer program. I find that the effect of the program on the share of eligible cars is significantly higher in the provinces with a larger number of qualifying car buyers.

The rest of this paper proceeds as follows. Section 2 describes the programs and potential effects of the programs in more detail. Section 3 presents the data. Section 4 provides the empirical methodology and estimation results, and Section 5 concludes.

2. Eco-car and first-car buyer excise tax rebate program

This section describes the eco-car policy and the first-car buyer excise tax rebate program.

2.1 Eco-car policy

To promote small and environmental friendly cars, in October 2009, the Finance Ministry of Thailand introduced a preferential excise tax rate of 17 per cent for eligible eco-cars. The normal excise tax rate that is applied for standard passenger cars is between 30% and 50%, depending on the engine size. An eco-car is defined as a car with an engine size smaller than 1,300cc for petrol engines and 1,400cc for diesel engines, that is fuel efficient (consuming less than 5 liters per 100 kilometers), and that complies with a minimum pollution standard of EURO4 or better (emitting no more than 120 grams of CO2 per kilometer). Moreover, the eco-car should satisfy passenger safety standards, both for front and side impact, as specified by the UN Economic Commission for Europe (UNECE) Regulations 94 and 95 respectively.

As a response to this policy, the first eco-car, the Nissan March, was released into the Thailand automobile market at a price of 459,000 baht. It was priced 17% lower than the Chevrolet Aveo 1,400 cc (550,000 baht), which is the next lowest price. Compared to a car at the median price, the Suzuki Swift and Honda Jazz 1,400 cc (599,000 baht), the March was priced 23.37% lower. The policy received a strong response from the market. The sales of eco-car models were over 7,000 cars within six months.

As of December 2012, there were 6 eco-car models released into the market (see Table 3.1). All of these eco-cars use a petrol engine. There was no diesel engine eco-car in the market at that time. Figure 3.1 displays the number of new eco-car registrations on a monthly basis from 2007 to 2012. The vertical dashed line represents the beginning of the eco-car policy. The data were obtained from Department of Land Transport in Thailand, which I describe in more detail in the next section. As shown in Figure 3.1, there is a noticeable increase in eco-car purchases after the program was launched.

Table 3.1: List of eco-car models

Make	Model	CC
NISSAN	MARCH	1198
SUZUKI	SWIFT	1242
HONDA	BRIO	1198
NISSAN	ALMERA	1198
HONDA	BRIO AMAZE	1198
MITSUBISHI	MIRAGE	1198

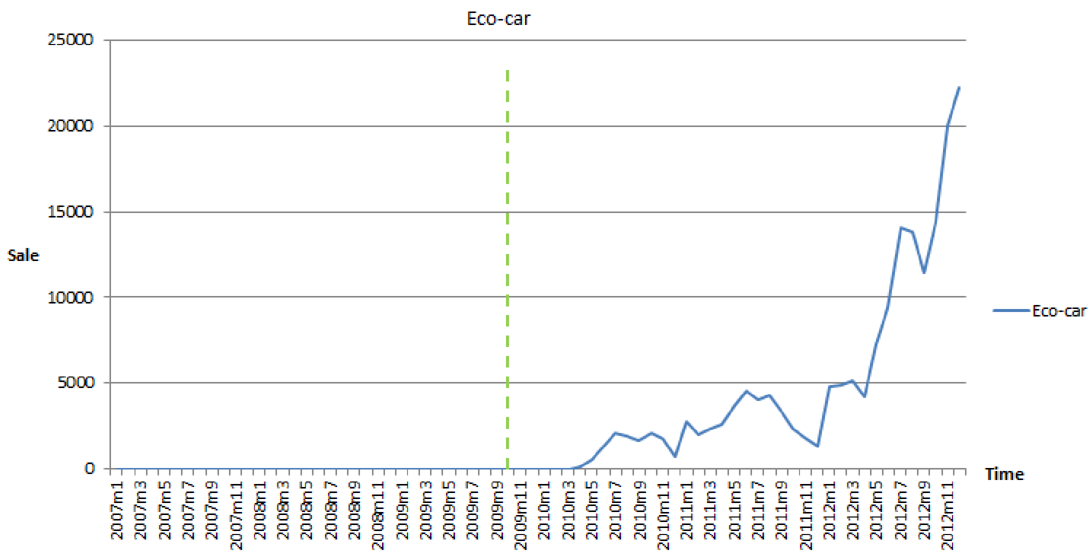

Figure 3.1: Eco-car purchases over time

2.2 First-car tax rebate policy

To stimulate the automotive industry, at the end of 2012, the government endorsed a first-car policy that returned the auto excise tax to persons that purchased their first car between September 16, 2011 and December 31, 2012. The policy applied to the purchase of vehicles under the following terms and conditions:

a) The vehicle engine capacity is smaller than 1,500 cc or is a double-cab pick-up truck with any engine capacity, but whose price does not exceed one million baht per unit.
b) The vehicles must be manufactured in Thailand.
c) Buyers must be 21 years of age or older and can seek a refund of the excise tax deduction up to one year after the purchase, but the refund must not exceed 100,000 baht.
d) Buyers are required to retain ownership of the new vehicle for at least five years.

Table 3.2 shows eligible vehicle models under the first car tax rebate policy and the amount of rebate for each vehicle model and style. It is worth noting that all eco-car models are eligible for the first car policy. Since the excise tax on eco-car models was already reduced to 17% prior to the first car policy, however, the amount of the excise tax rebate for eco-car models under the first car policy is lower than the rebate for other eligible vehicle models.

The response to the first car policy is also noticeable. Figure 3.2 displays the number of new cars registrations of eligible and non-eligible[26] vehicle models during 2007-2012. The vertical dashed line and the solid line represent the beginning of eco-car policy and the beginning of the first car policy respectively. It is obvious that sales of cars that were eligible for the first car policy increased dramatically after the policy. Sales of car that were not eligible for the first car policy show no deviation from their trend.

3. Data

This study uses the data of new vehicle registrations as a proxy for vehicle sales. The data of new vehicle registrations were obtained from Department of Land Transport, using the data for sedans under 1600 cc (less than 7 passengers). Since the Department of Land Transport only

[26] Lists of eligible and non-eligible car model are shown in Table C.1 in appendix.

has monthly provincial level data for sedans under 1600 cc[27], other models will be omitted in this study. The data is collected for each 76 provinces and available from Jan 2007 to Dec 2012. In 2011, a new province, Bungkan, was established by separating from Nongkai province. Since this study covers periods both before and after the separation, I put the data of Bungkan back to Nongkai province. All registered vehicles are broken down by make, broad vehicle model or nameplate, and the size of the engine (cc). For example, a 1,400 cc Aveo made by Chevrolet is one model, while a 1,600 cc Aveo is a different model. A total of 23 vehicle models are included in this study, and each of them has at least 1% sales share in at least one year during 2007 – 2012. These 23 models account for 96% of total car sales among models with 1,600 cc engines or smaller. Information on make, nameplate, and cc for all 23 models are presented in Table C.1 in the appendix to this chapter.

Table 3.2: Incremental subsidy for eligible models

Make	Nameplate	CC	Eco-car	Rebate (baht)
HONDA	BRIO	1198	Yes	63,000-73,000
MITSUBISHI	MIRAGE	1198	Yes	55,000-77,000
NISSAN	ALMERA	1198	Yes	60,000-84,000
NISSAN	MARCH	1198	Yes	53,000-79,000
SUZUKI	SWIFT	1242	Yes	65,000-79,000
KIA	PICANTO	1248	Yes	54,000-80,000
FORD	FIESTA	1388	No	100,000
KIA	RIO	1396	No	100,000
CHEVROLET	AVEO	1398	No	100,000
CHEVROLET	SONIC	1398	No	100,000
HONDA	JAZZ	1497	No	100,000
HONDA	CITY	1497	No	100,000
TOYOTA	YARIS	1497	No	100,000
MAZDA	MAZDA 2	1498	No	100,000

27 In 2010, new vehicle registrations for vehicles smaller than 1600cc covered about 50% of total new vehicle registrations (for vehicles with capacity less than 7 passengers).

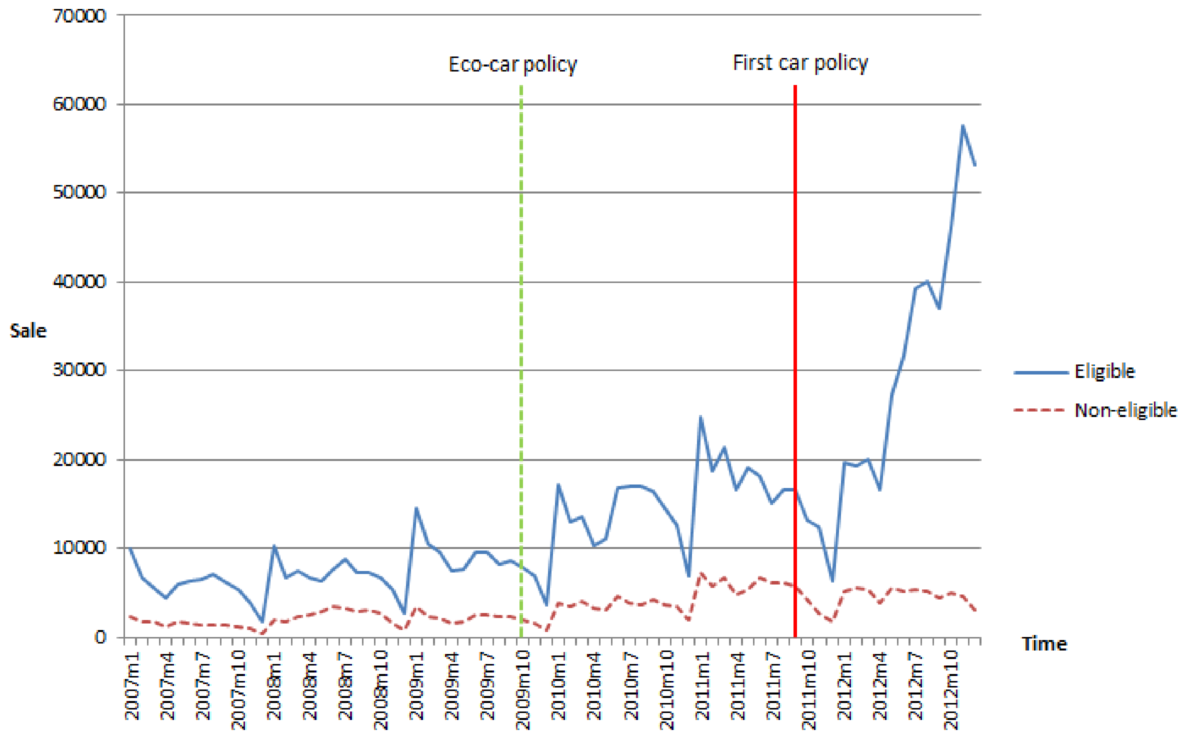

Figure 3.2: Eligible and non-eligible car sales over time

Among these 23 models, 11 models are eligible for the first car rebate policy, and five of them are eco-car models. Figure 3.3 shows the share of eligible car sales as a fraction of sales for all 23 models, as well as the share of eco-car sales as a fraction of sales for all eligible models over time. Prior to the first car policy, the share of eligible car seems to fluctuate around 0.8. However, a positive trend in the share of eligible car sale is noticeable after the policy. The share of eco-car sales seems to have a similar positive trend before and after first car policy.

Information about the attributes of each car model was obtained from www.redbookasiapacific.com/th. Redbook (Automated Data Services Pty Ltd) is a known company for providing vehicle specification and price information in Australia, New Zealand, Malaysia,

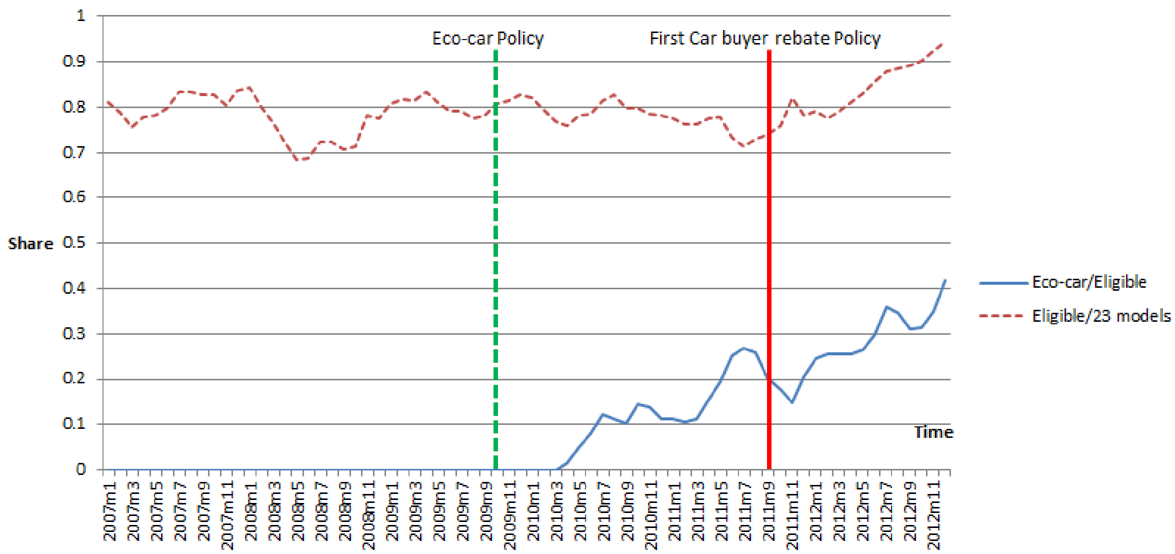

Figure 3.3: Share of eligible car sales to all 23 models, and share of eco car sales on eligible models over time.

Thailand, and China. In Thailand, information is available for all vehicles in the market since 1992. Since the data for new vehicle registrations from Department of Land Transport does not include body style, I used the attributes of base style with automatic transmission for each model. Information on attributes includes vehicle length (mm), width (mm), height (mm), curb weight (kg), and fuel tank capacity (liters). However, the information obtained from Redbook websites did not contain vehicle fuel efficiency (liter per kilometer or lpk). Therefore, I use the data of lpk and other vehicle attributes for a vehicle in 2014 obtained from other websites (e.g. www.checkraka.com). I use the attributes and fuel efficiency of these 2014 models to predict the fuel efficiency as a function of vehicle attributes acquired from Redbook in 2007-2012. The prediction method and results are shown in the next section.

For gasoline prices, I use the national nominal price of Benzene 91 (baht per liter) from January 2007 to December 2012, which I converted to real prices using the consumer price index

(CPI) obtained from Bank of Thailand. Figure 3.4 shows the variation in real gas price over the period of study.

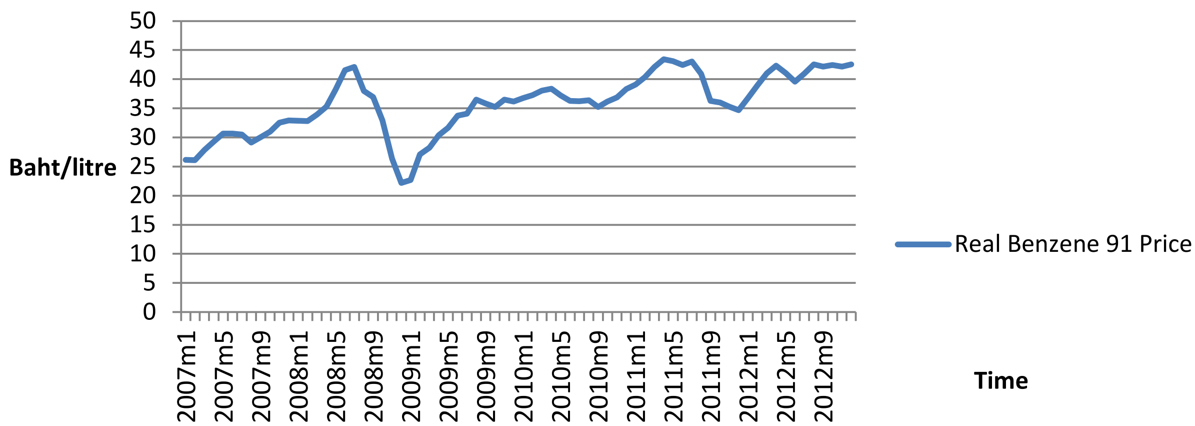

Figure 3.4: The variation of gas price over time

4. Empirical methodology and estimation results

In this section, I first discuss the channels through which the program could affect the share of eco-car sales. Then, I describe the empirical methodology and results.

4.1 Effect of first-car excise tax rebate policy on eco-car sales

The first-car excise tax rebate scheme may have unintended effects on eco-car sales. The excise tax rebate is lower for eco-car models. Thus, prices decreases more for eligible non eco-cars models in the presence of the subsidy. People who had previously intended to buy an eco-car might therefore deviate from their decision. Thus, in this case, the first car buyer policy might decrease the share of eco car sales.

However, the lower price of eco car (after the excise tax rebate) may induce a higher demand due to its affordability. People who had not previously planned to buy a new car might encouraged to buy a car, and the eco-car seems to be the first choice for low-income people, since it is very affordable. For example, people who cannot afford a car (at 450,000 baht) are now able to purchase a Nissan March at less than 400,000 baht. In this case, the first car buyer policy might increase the share of eco-car sales.

Table 3.3 shows vehicle prices before and after the rebate for eligible car models. The price and rebate information are for a base style with automatic transmission for each vehicle model in January 2012.

Table 3.3: Vehicle price before and after the rebate in January 2012

Make	Nameplate	cc	Price (baht)	Eco	Rebate	Price after rebate
NISSAN	MARCH	1198	459,000	Yes	65,000	394,000
NISSAN	ALMERA	1198	489,000	Yes	69,000	420,000
MITSUBISHI	MIRAGE	1198	460,000	Yes	69,000	391,000
HONDA	BRIO	1198	473,000	Yes	72,000	401,000
SUZUKI	SWIFT	1242	469,000	Yes	72,000	397,000
CHEVROLET	AVEO	1399	550,000	No	100,000	450,000
HONDA	CITY	1497	599,000	No	100,000	499,000
HONDA	JAZZ	1497	630,000	No	100,000	530,000
TOYOTA	YARIS	1497	574,000	No	100,000	474,000
TOYOTA	SOLUNA	1497	564,000	No	100,000	464,000
MAZDA	MAZDA 2	1498	580,000	No	100,000	480,000
FORD	FIESTA	1388	584,000	No	100,000	484,000
FORD	FIESTA	1596	644,000	No	100,000	544,000
FORD	FIESTA	1499	644,000	No	100,000	544,000
CHEVROLET	AVEO	1598	649,000	No	100,000	549,000

4.2 Empirical methodology

I estimate a reduced-form model for the effects of the first-car tax rebate program on eligible cars and eco-car sales, controlling for vehicle model and province-time effects. The province-time dummies can be treated as a market fixed effect, which will capture unobserved movements in the outside good (Huang and Rojas 2013). The baseline specification is then:

$$\ln share_{jpt} = \alpha + \beta_0 FirstCar_{jt} + \beta_1 FirstCar_{jt} EcoCar_{jt} + \gamma lpk_{jt} \cdot GasPrice_t + \delta_j + \theta_{pt} + \varepsilon_{jpt}, \quad (1)$$

where $share_{jpt}$ is the share of vehicle model *j* sales in province *p* at time *t*. $FirstCar_{jt}$ is the policy dummy variable, which equals one for any vehicle model *j* that is eligible for the first-car buyer program from September 2009, and zero otherwise. $EcoCar_{jt}$ is a dummy variable for eco-car models. δ_j is a vehicle model effect that captures brand or perceptions of an individual model's quality. θ_{pt} is a province-time effect that captures the outside good, and which also controls for unobservable effects, such as demand shocks at the province level. Lastly, ε_{jpt} is the error term.

I do not include $EcoCar_{jt}$ in the equation (except when it interacts with the $FirstCar_{jt}$ dummy) since all eco-car models are introduced to the market after the eco-car policy started in October 2009. Thus, variation in the $EcoCar_{jt}$ dummy comes only from the variation in vehicle model, which is already captured by the vehicle model fixed effect.

To control for other characteristics that are responsible for the differential purchase patterns in eligible and non-eligible vehicle models, I include vehicle characteristics that are likely to affect the car sales. I use $lpk_{jt} \cdot GasPrice_t$ as a control variable, where lpk_{jt} is liters per kilometer, which varies across vehicle models and over time. $GasPrice_t$ is the fuel price in real terms. Thus, $lpk_{jt}GasPrice_t$ measures the energy costs of running vehicle model j for 1 kilometer. Since data for lpk are only available for some vehicle models (from 32 models) in 2014, I use vehicle attributes and lpk information for these models to predict lpk as a function of vehicle attributes. To estimate the relationship between kpl (or 1/lpk) and other vehicle attributes, I assume the Cobb-Douglas functional form (Knittel, 2011). Thus, fuel economy is modeled as:

$$\ln kpl_j = \beta_0 + \beta_1 lnwidth_j + \beta_2 lnheight_j + \beta_3 lnweight_j + \beta_2 lncc_j + \varepsilon_j\,, (2)$$

where kpl_j is kilometer per liter of vehicle model j. Width, height, weight, and cc are the information of width, height, weight, and cc of vehicle j, respectively. Estimates for equation (2) are shown in Table D.1 in appendix to this chapter.

Results from estimating equation (1) are presented in Table 3.4. The first specification includes the first car policy dummy, an interaction between the first car policy and the eco car policy, and province-time and vehicle model fixed effects. The second specification adds control variable. The standard errors in both specifications are clustered at the province level. I find that the first car tax rebate policy significantly increases the share of eligible vehicles in both specifications. In addition, the coefficient values are around 0.18-0.21. The coefficient on the interaction between the first car and eco-car policy is negative, but small and statistically insignificant in all specifications. In other words, the first car buyer policy does not significantly detract from eco-car sales, on net.

The impact of the rebate policy on a given province might depend heterogeneously on the number of qualifying car buyers for the first-car buyer program. The effect in the provinces with more qualifying buyers should be higher than in provinces with fewer qualifying buyers. I account for this issue by including a variable that measures exposure to the first-car buyer

Table 3.4: Baseline results

VARIABLES	(1) lnshare	(2) lnshare
Firstcar	0.2106***	0.1787***
	(0.0290)	(0.0287)
Firstcar*Ecocar	-0.0139	-0.0014
	(0.0376)	(0.0373)
lpk*gas price		-1.2840***
		(1.8805)
Constant	-2.1954***	0.1444
	(0.0573)	(0.3616)
Model effects	Yes	Yes
Province-time effects	Yes	Yes
Observations	52,970	52,970
R-squared	0.6787	0.6794

Note: Robust standard errors in parentheses, cluster at province level

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

program in the analysis. To measure exposure to the program, I construct a new variable called *exposure* as:

$$exposure_p = pop20up_p - car\ stock_p\ ,$$

where $pop20up_p$ is the number of people older than 20 years in province p in 2010. Although eligible buyers for the first-car buyer program must be 21 years or older, there is no data available on the population older than age 21. Thus, I use the population over age 20 as a proxy variable. The variable $car\ stock_p$ is the number of all private vehicles[28] that were registered in province p as of December 2010. The data for the population older than 20 years old were obtained from the Department of Provincial Administration. The data for the car stock as of December 2010 come from the Department of Land Transport. I focus on population and car

28 Private vehicles include private sedans (less than 7 passengers), private microbuses and passenger vans, and private vans and pick-up trucks.

stock in 2010, since these numbers were pre-determined at the time of the first-car policy in 2011.

To facilitate interpretation, I rescale the exposure variable to have a mean of zero and a standard deviation of one. Then, I interact the exposure variable with all policy variables to equation (1). Thus, I estimate the following specification:

$$
\begin{aligned}
ln\, share_{jpt} = \alpha + \beta_1 FirstCar_{jt} + \beta_2 FirstCar_{jt} \cdot EcoCar_{jt} + \beta_3 exposure_p \cdot FirstCar_{jt} \\
+ \beta_4 exposure_p \cdot EcoCar_{jt} + \beta_5 exposure_p \cdot FirstCar_{jt} \cdot EcoCar_{jt} + \gamma lpk_{jt} \\
\cdot GasPrice_t + \delta_j + \theta_{pt} + \varepsilon_{jpt} \qquad (3)
\end{aligned}
$$

Table 3.5 shows the estimation results for equation (3). The estimate of β implies that the first-car policy leads to a 15.7% increase in the share of eligible car in a province with mean exposure. In a province with exposure one standard deviation above the mean, however, the effect of the policy is almost doubled (i.e., $\hat{\beta}_1 + \hat{\beta}_3 = 0.1570 + 0.1333 = 0.2903$). Put simply, the effect of the policy on the share of eligible vehicles is higher in the provinces which have more qualifying buyers. The coefficients on the interactions between exposure and the other policy variables are small and insignificant. These results are consistent with the results in Table 3.4.

5. Conclusions

In this paper, I use monthly data on new car registrations to estimate reduced-form models for the effects of the first car buyer tax rebate policy on the share of eligible cars and the share of eco-car sales. The estimation results indicate an 18% relative increase in the share of eligible cars sales after the introduction of the policy in September 2011. However, I do not find significant change in the share of eco-car sales after the first car policy was introduced. To address the potentially heterogeneous effect of the program due to different numbers of qualifying buyers in each province, I model exposure to the first-car buyer program. I find that the effect of program on the share of eligible cars is significantly higher in the provinces with a larger number of qualifying car buyers.

Table 3.5: Heterogeneous effects by exposure

VARIABLES	(1) lnshare
Firstcar	0.1570***
	(0.0348)
Firstcar*eco	0.0005
	(0.0382)
Firstcar*exposure	0.1333***
	(0.0234)
Eco*exposure	-0.0273
	(0.0315)
Firstcar*eco*exposure	-0.0204
	(0.0268)
lpk*gas price	-1.3044***
	(1.8781)
Constant	0.1864
	(0.3594)
Model effects	Yes
Province-time effects	Yes
Observations	52,970
R-squared	0.6802

Note: Robust standard errors in parentheses, cluster at province level

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

APPENDIX

Table C.1: Information on make, nameplate, and cc for all 23 models used in this study

	Make	Nameplate	cc	Eco-car	First car eligible
1	CHEVROLET	AVEO	1399	No	Yes
2	CHEVROLET	OPTRA	1598	No	No
3	HONDA	CITY	1497	No	Yes
4	HONDA	JAZZ	1497	No	Yes
5	MITSUBISHI	LANCER	1584	No	No
6	TOYOTA	AVANZA	1495	No	No
7	TOYOTA	YARIS	1497	No	Yes
8	TOYOTA	SOLUNA	1497	No	No
9	NISSAN	TIIDA	1598	No	No
10	TOYOTA	COROLLA	1598	No	No
11	MAZDA	MAZDA 3	1598	No	No
12	MAZDA	MAZDA 2	1498	No	Yes
13	HONDA	FREED	1497	No	No
14	NISSAN	MARCH	1198	Yes	Yes
15	SUZUKI	SWIFT	1490	No	No
16	FORD	FIESTA	1388	No	Yes
17	FORD	FIESTA	1596	No	No
18	CHEVROLET	AVEO	1598	No	No
19	HONDA	BRIO	1198	Yes	Yes
20	NISSAN	ALMERA	1198	Yes	Yes
21	SUZUKI	SWIFT	1242	Yes	Yes
22	FORD	FIESTA	1499	No	No
23	MITSUBISHI	MIRAGE	1198	Yes	Yes

Table D.1: Estimation of log (kpl)

VARIABLES	lnkpl
Lnwidth	0.211
	(0.735)
Lnheight	-1.476***
	(0.370)
Lnweight	-0.0954
	(0.245)
Lncc	-1.102***
	(0.123)
Constant	20.64***
	(5.633)
Observations	32
R-squared	0.665

Note: Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

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