Econometric analyses of renewable energy promotion

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Abstract

This thesis consists of four self-contained papers related to renewable energy promotion.

Paper I analyzes the factors that influence the share of renewable energy in total energy supply. The analysis is conducted using a panel data consisting of 26 OECD countries over the period 1990-2010. The results from the two-way fixed effect model indicate that policy measures play important roles in increasing the share of renewable energy. A positive effect of Research and Development (R&D) on the share of renewable energy is found, and this is because R&D activities have reduced the cost of renewable energy production. The results also indicate that having a market-based policy instrument (feed-in tariffs or quota obligations) in place increases the share of renewable energy in a country. However, there is no evidence to prefer a feed-in tariff or a quota obligation in this study. The individual effect of these policy instruments is not significant. This may issue from lack of powerful variables to measure their magnitudes. In addition, a large energy consumption growth decreases the share of renewable energy in total energy supply.

Paper II elicits the value of renewable electricity that people are willing to pay to have their electricity supply come from exclusively renewable sources in six OECD countries. The results indicate that people are willing to pay only a few percentage points more of their current electricity bill in each country. This suggests that it is still difficult to extract a sizable premium for renewable electricity.

Paper III investigates motivations for adoption of renewable electricity among households in Sweden. Different models are used to consider the possible interactions between adopting renewable electricity and joining environmental organizations. The results indicate that people’s residences and most socio-demographic characteristics do not affect their adoption of renewable electricity. Adopters of renewable electricity tend to be males, members of environmental organizations, and those who strongly agree that people should pay for environmental policies. Environmental concern also affects adoption of renewable electricity, mainly via membership in an environmental organization.

Paper IV investigates determinants of people’s participation in environmental organizations in Sweden with a zero-inflated ordered probit (ZIOP) model. This model can account for different types of non-members, i.e. those who might become members in the future and those who are unlikely to become a member. The differentiation is based on a two-stage decision on participation. Results indicate that different factors influence people’s decision in the two stages, and a factor could have different effect in the two stages. Attitudes towards the environment play an important role. The component of non-members varies among households of different income levels.

Keywords: renewable energy, policy measures, willingness to pay (WTP), environmental organization, households

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Dedication

To my father

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Shi, L.. The share of renewable energy and policy support (manuscript).

II Shi, L., Zhou W. & Kriström B. (2013). Residential demand for green electricity. *Environmental Economics* 4(1), 51-62.

III Shi, L.. What motivates households to adopt renewable electricity? (manuscript).

IV Shi, L.. Participation in environmental organizations: who and how? (manuscript).

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Abbreviations

CDD	cooling degree days
CRES	Contribution of renewables to energy supply
EPIC	Environment Policy and Individual Behaviour Change
HDD	heating degree days
IIA	independence of irrelevant alternatives
RPS	Renewable Portfolio Standard
R&D	Research and Development
TGCs	Tradable Green Certificates
WTP	Willingness To Pay
ZIOP	Zero inflated ordered probit model

1 Introduction

Renewable energy[1] is derived from natural processes that are replenished constantly and sustainably such as sunlight, wind and plant growth. Renewable energy provides many benefits. First, compared to fossil fuel which is finite, energy from renewable sources is sustainable and will never run out. Second, renewable energy from non biomass sources produces little or no carbon dioxide, so it has a minimal impact on the environment. Third, by building and maintaining the facilities, it can also create jobs and bring economic benefits, especially the regional areas located far away from urban centers. Last but not least, diversifying energy sources increases a country's energy independence and security where a large fossil fuel import is needed, and it also could help to avoid volatility of energy price. Renewable energy is one of the most important solutions to current environmental problems, and the exploitation of renewable energy is a key part of sustainable development (Dincer, 2000).

Renewable energy mainly replaces conventional energy (fossil and nuclear fuels) in power generation, heating, and transport fuels. Capacity of many renewable energy technologies grew rapidly, with the fastest growth in the power sector. According to REN21 (2013), from 2008 to 2012, total capacity of solar photovoltaics, concentrating solar thermal power, and wind power increased 60%, 40% and 25% respectively. The growth of more mature technologies has been modest, such as hydropower, geothermal power and biopower. Energy from renewable sources supplies 19% of global final energy consumption in 2011. Traditional biomass is primarily used for cooking and heating in rural areas of developing countries. Although traditional biomass accounts for 9.3% of global final energy consumption, it is growing slowly or even declining in some regions. Hydropower, which is growing modestly, is the second largest renewable energy source. It accounts for 3.7% of global

[1] Energy from some renewable sources is not "green", such as large hydro, but "renewable" is equivalent to "green" in the thesis, for simplicity.

final energy consumption and a much bigger share in electricity generation (16.5% by end of 2012). Energy from other renewable sources including wind, solar, geothermal and marine power is growing very quickly.

A main reason for a small share of renewable energy in the energy mix is that most renewable energy technologies are relatively costly, which makes it less competitive with conventional energy such as oil, natural gas and coal. There is not much incentive for suppliers to invest in it. More and more governments have taken various supporting measures to make renewable energy more competitive and create a market for it. International energy agency (IEA) categorizes these supporting measures into six groups: economic instruments, information and education, policy support, regulatory instruments, Research, Development and Deployment (RD&D), and voluntary approaches (IEA, 2014). Each category consists of several policy measures. Public R&D support is important in the cost reduction process (Ek & Söderholm, 2010). Feed-in tariffs and quota obligations aim to stimulate investment in renewable energy through regulating tariffs or quotas. A feed-in tariff is a relatively high, guaranteed price for renewable electricity set by government to encourage production. A quota obligation supports renewable electricity generation through directly setting a quota of renewable electricity. For example, Sweden introduced Tradable Green Certificates (TGCs) in 2003 to support biofuels, wind power, existing small hydropower and new hydropower. Retailing companies are required to buy a certain percentage of total electricity from renewable sources, in terms of certificates. Electricity generators can receive extra income by selling the certificates based on the amount of the renewable electricity they feed into the grid. One MWh of renewable electricity generated corresponds to one TGC. So the generators of renewable electricity benefit from both selling electricity on the electricity wholesale market and selling certificates on the TGC market.

EU has set a target to ensure that 20% of final energy consumption comes from renewable sources by 2020. This target is then translated to individual targets for each member country. The percentages required in individual countries are based on their starting point and potential of renewable energy. According to the government offices, Sweden aims at a target of 49% of final energy consumption from renewable sources. Besides the EU countries, many other countries have similar targets, mostly defined as the share of electricity or primary energy supply. These targets essentially require a growth in generation of renewable energy and a transformation to cleaner and more diverse energy sources. To efficiently achieve these targets, it is necessary to know which factors have affected this "greening" process in recent decades. As governments have intervened in energy markets with various policy measures, the knowledge about whether implementation of these policy measures results in an increase in the share of renewable energy is important to guide development of renewable energy in the future.

Besides the various policy measures that are used to promote renewable energy generation, renewable energy market also can be driven by consumer demand. About one-fifth of total global energy is used for the residential sector (Brounen *et al.*, 2012). In the OECD, about one third of electricity is used in the residential sector and this proportion increased by 2.8% per annum between 1973 and 2010, in comparison with 1.3% in industry sector (IEA). The residential sector is considered to play an increasingly important role in the energy market and it is a key part of any comprehensive energy policy package (OECD, 2011). Given that, two papers of the thesis investigate residential demand for renewable electricity.

In a competitive market, consumers have the right to choose their electricity supplier, products, and even sources of electricity. Due to costly technologies, renewable energy is generally provided with a higher price compared to conventional energy. But if consumers think the benefit of renewable energy worth the premium, they are likely to buy it. To make policies that can effectively increase demand of renewable electricity, it is important to know how much consumers are willing to pay for renewable electricity. This knowledge is also important for electricity companies to extract a proper premium making profits and acceptable by the public.

For the countries having quota obligations in place, achievement of the target of renewable energy can be realized through adjusting the quota, and do not solely rely on consumers' voluntary purchases. However it is still important to have a better understanding of the voluntary purchase. When a significant proportion of consumers adopt renewable electricity, a contribution is made which can be further invested into renewable energy production. This helps to increase the share of renewable energy in the future. The knowledge about motivations for people's voluntary purchase could provide further policy implications for those countries with a quota obligation supporting scheme. One motivation for individuals' demand for renewable electricity could be environmental preferences. Kotchen & Moore (2008) use membership in an environmental organization to classify conservationists and nonconservationists with different patterns of consumer behavior. Members are concerned about the effect of their consumption decisions on the environment, and they are found to be more likely to participate in green electricity programs. This implies the significance of better understanding the relationship between membership in environmental organizations and adoption of renewable electricity.

Since demand for renewable electricity could be correlated with membership in environmental organizations, the knowledge about which factors affect people's engagement in environmental organizations may be interesting for policymakers. This knowledge is also essential for environmental organizations to attract more participants, because most environmental organizations are non-profit and they rely on the donation and volunteering efforts of members to survive and develop.

From a supply perspective, paper I investigates factors that influence the share of renewable energy in total energy supply in OECD countries. It adds empirical evidence to the knowledge about effectiveness of policy measures in increasing the share of renewable energy. The other three papers focus on the demand side. Paper II elicits the value of renewable electricity in the residential sector in six OECD countries in a way that solves a problem that an increased price implies lower consumption. Using a multi-country survey, it explores within-country variation of WTP for each country investigated. Paper III further investigates motivations for signing up for renewable electricity in Sweden. It addresses the problem relating to interaction of adoption of renewable electricity and membership in environmental organizations. Due to the impact of membership on residential demand for renewable electricity, paper IV models participation in environmental organizations. A two-stage decision is assumed to account for different types of non-members. It adds to the knowledge about the decision-making process of participation and reveals motivations of decisions in the two stages.

2 Objectives

The main objective of this thesis is to acquire new knowledge and better understanding of how to promote renewable energy from supply side and demand side. This thesis aims to assess the effectiveness of the popular incentive measures (R&D, feed-in tariffs, and quota obligations) in increasing the share of renewable energy in total energy supply.

From the demand side, this thesis aims to investigate households' preference for renewable electricity in the residential sector: how much are they willing to pay for renewable electricity? Which factors are correlated with WTP? This thesis also aims to find out which factors motivate people to voluntarily purchase renewable electricity in a real market. The purpose is to examine whether the motivations of actual adoption are consistent with those affecting WTP.

Another objective of this thesis is to model people's participation in environmental organizations, since membership influences household demand for renewable electricity. It aims to have a better understanding of participation: Who tend to participate? What motivates them, and how?

3 Literature

3.1 Renewable energy and policy support

The expanding of renewable energy across the world is not sufficient (Jefferson, 2006). Market barriers, economic and financial barriers, institutional barriers, and technical barriers prevent penetration of renewable energy into energy markets (Painuly, 2001). The effect of these barriers may vary across technologies and countries. The drivers of development of renewable energy are also discussed in many studies. Drivers such as Renewable Portfolio Standards (PRS), financial incentives, consumer demand for green power, natural gas price volatility, and wholesale market rules are identified (Bird *et al.*, 2005). The various drivers function as a whole package that contributes to successful development in installed wind capacity in the US. Alagappan *et al.* (2011) review 14 markets in North America and Europe, and high feed-in tariffs, easy transmission access, and low transmission charges are found to promote renewable energy. Some other factors are also suggested to be important, such as GDP, energy consumption, and energy import (Popp *et al.*, 2011; Carley, 2009; Marques & Fuinhas, 2011; Marques *et al.*, 2010).

Policies are considered to play important roles in development of renewable energy in various countries (Jacobsson & Lauber, 2006; Winkler, 2005; Tan *et al.*, 2008; Peidong *et al.*, 2009; Mitchell & Connor, 2004). Some papers compare price-based instruments and quantity-based instruments from an international perspective (Lewis & Wiser, 2007; Jacobsson *et al.*, 2009; Haas *et al.*, 2004). There is controversy about which policy instrument should be adopted. Mitchell *et al.* (2006) argued that a feed-in tariff system is more effective to increase the share of renewable energy because it provides different kinds of risk reduction in terms of price, volume and balancing risk. Böhringer *et al.* (2007) indicate that a tradable green quota is an effective way to reach the European target of "greening" electricity. Menanteau *et al.* (2003)

examine concrete examples and conclude that a system of feed-in tariff is more efficient than a bidding system. It is also indicated that the efficiency of green certificates has not been proven due to limited experience.

Effectiveness of various policy measures is examined by some empirical studies. Popp *et al.* (2011) indicate that investment in renewable energy capacity across 26 OECD countries owns much to technological innovation, rather than individual policies. Kobos *et al.* (2006) suggest that recent growth in US wind energy installations is more a result of financial incentives and capital cost reductions from abroad than of technology innovation. It is further suggested that if without sustained federal R&D and commercial marketplace, it may take a longer time to achieve cost reductions and further market adoption. Marques & Fuinhas (2012) examine several categories of supporting policies in EU countries between 1990 and 2007. Incentives/subsidies (including feed-in tariffs) and policy processes that define strategies and outline specific programs are indicated to be drivers for renewable energy. Market deployment policies are found to have significant impact on per capita supply of both renewable energy and bioenergy (Gan & Smith, 2011), and the effect of other policies (e.g. R&D and market-based policies) are not significant. The effectiveness of Renewable Portfolio Standard (RPS), which is a quota obligation scheme across states in the US, is examined (Carley, 2009). The RPS is found to increase the total amount of renewable energy generation, but it is not a predictor of the share of renewable energy in the total energy mix. Shrimali & Kniefel (2011) investigate the effectiveness of policies on the penetration of various emerging renewable electricity sources. The RPS has a significant impact on the penetration of renewable energy, but this effect depends on the types of renewable sources. Voluntary renewable portfolio standards and green power purchasing programs are found to be ineffective in increasing any type of renewable energy.

Most of the empirical studies have focused on a single policy instrument in one country, or policies of broader categories. An investigation of concrete policy measures may provide more clear implications. Except a study that examines the effect of individual policy measures on technology innovation (Johnstone *et al.*, 2010), few studies examine effectiveness of R&D, feed-in tariffs, and quota obligations all at once. Accordingly, this is what paper I seeks to address. It tries to provide some evidence for the theoretical debate on their effectiveness.

3.2 Theoretical framework

Pro-environmental behavior has mainly been studied from perspectives of economics and psychology, and this is well reviewed by Turaga *et al.* (2010). In economics, pro-environmental behaviors are perceived as a contribution to a public good (Clark *et al.*, 2003). This implies that once the public good is provided, the individuals who do not contribute also can benefit from it. As a result, a rational person has little incentive to contribute, and chooses to act as a free rider. But empirical data supports some voluntary contribution to public goods, such as provision of renewable energy and environmental organizations. Economists have extended the standard models to incorporate "impure altruism" (Andreoni, 1990) to explain this. People who contribute are rewarded an additional "warm glow" benefit, which is a motivation for contribution to a public good.

Voluntary contributions to a public good can be motivated by perceived social responsibility (Brekke *et al.*, 2003; Nyborg *et al.*, 2006). The decision depends on tradeoffs between the benefit of a "good image" and the cost of contribution. This model implies that economic incentives may have adverse effects on voluntary contributions, e.g. recycling and voluntary community work. Based on this model, Ek & Söderholm (2008) investigate the determinants of choosing green electricity among Swedish households. Besides the perceived personal responsibility and the perceived consumer effectiveness, the impact of purchasing on the household budget influences willingness to contribute. Some studies incorporate different motivational assumptions to explain heterogeneity of pro-environmental behavior. Chouinard *et al.* (2008) develop a multi-utility model that can identify different types of farmers who value environmental effects. One type of farmers maximizes the utility only from a direct personal benefit. The utility function of another type of farmers has a self interest dimension and a social dimension.

While economics rely on the concept of preferences and the utility maximization model, psychologists assume that behaviors are predicted by attitudes. A range of studies focused on the role of moral norms and beliefs about environmental conditions and personal responsibility which are based on the norm-activation theory (Schwartz, 1977; Schwartz & Howard, 1981) or the value-belief-norm theory (Stern & Dietz, 1994; Stern *et al.*, 1999). These theories have been adopted to explain environmental citizenship (Stern *et al.*, 1999), acceptability of policies to reduce household carbon emissions (Steg *et al.*, 2005) and willingness to reduce personal car use (Nordlund & Garvill, 2003). The pro-environmental behavior with high costs or strong constrains appear to be better explained with the Theory of Planed Behavior (Ajzen, 1991). The motivational factors are captured by an individual's behavioral intention. It is assumed that intention affects likelihood of actually performing that behavior.

3.3 Residential demand for renewable electricity

Measuring the economic value of benefits from using renewable electricity could provide information of the location and slope of the demand curve for renewable energy. Many studies from different countries try to estimate a value on the price premium of renewable electricity. The concept of consumers' WTP is the cornerstone principle in measuring the benefits (Brent, 2007). Although different methods are used, positive WTP values for renewable electricity are usually concluded. Fouquet (1998) cites a survey and indicates that one-fifth of the participants would pay a premium in the UK, and 5% would pay more than a 20% premium. Farhar (1999) uses a market survey of the US to derive a kind of demand curve. The data suggests that 70% of residential consumers would pay \$5 per month, 38% would pay \$10 per month, and 21% would pay \$15 per month. The derived aggregated WTP curve suggests an exponential fit of the data. Batley *et al.* (2001) indicate that 34% of Leicester population would like to pay and this proportion is higher than the national average of the UK. Over half of consumers in Luxembourg, Netherlands, Sweden and Denmark are willing to pay a premium (Devries, 2004).

Roe *et al.* (2001) analyze the US consumers' demand for environmental attributes of deregulated residential electricity service. The attributes include price, contract terms, fuel source mix and air emission vector. The authors suggest that for several groups, certain premiums may be charged for emissions reduction stemming from increased reliance upon renewable fuels. Information from the supply side regarding premium, fuel mix, and certification was also used in a hedonic regression to predict the marginal price premium from increasing new renewable sources. Yoo & Kwak (2009) examine the WTP in South Korea. The monthly mean WTP estimates derived from parametric and non-parametric methods were KRW 1681 (USD 1.8) and KRW 2072 (USD 2.2), respectively.

These WTP estimates are mean or median value, and people's WTP is correlated with several parameters. Higher income earners generally express a higher WTP (Diaz-Rainey & Ashton, 2007; Kotchen & Moore, 2007; Zarnikau, 2003). But a negative correlation between income and attitudes to wind power is found by Ek (2005). The author explains it with the fact that people with lower income focus on the jobs opportunities brought by the wind power installations. A higher WTP is indicated by young people (Zorić &

Hrovatin, 2012; Gerpott & Mahmudova, 2010), people who are well educated (Rowlands *et al.*, 2003; Zarnikau, 2003), and members of environmental organizations (Diaz-Rainey & Ashton, 2011). There is also a correlation between WTP and attitudinal variables such as environmental concern, altruistic attitudes, and perceived consumer effectiveness (Ertör-Akyazı *et al.*, 2012; Diaz-Rainey & Ashton, 2011; Kotchen & Moore, 2007).

WTP could also be affected by the methods of provision and payment mechanism (Wiser, 2007). A collective payment could effectively prevent free-riding. A higher WTP is stated under a collective payment mechanism than that of a voluntary payment. In addition, WTP under a private provision mechanism is found to be higher than that of a government provision. An important study about the underlying preferences is conducted by Cameron *et al.* (2002). Using different value elicitation methods, the authors combine one telephone survey with six mail surveys in cooperation with a power company of New York State. Seven independent samples of respondents were asked to consider additional charges for this company to plant trees or providing renewable electricity. An innovative feature of this research is that each survey is conducted with a unique method. The results show that at least four of these seven elicitation methods have a common indirect utility-difference function, in spite of individual differences in separate samples.

Jensen *et al.* (2004) note that people have different preferences across types of renewable energy. The value on solar and wind (12-15 USD) is higher than bio energy (7 USD). Borchers *et al.* (2007) find that in the US solar is preferred over a generic green and wind; biomass and farm methane are the least preferred sources. Hanley & Nevin (1999) evaluate three renewable energy options in remote communities in Scotland. Small-scale hydro and wind farm is more supported than biomass schemes. The mean WTP for small scale hydro across the whole sample is the highest.

Although a sizable proportion of consumers state that they are willing to pay more for renewable energy, the real market shows quite different data. Bird *et al.* (2002) review international green power marketing activities by 2002 and the market penetration rates have been typically been in the order of 1%. A successful market example is Netherlands where 13% of residential customers had chosen green power. Graham (2006) estimates that the percentage of residential adoption in Great Britain is less than 1% by 2006. The penetration rate ranges from 1.7% to 2.5% across states of the US in 2009 (Bird & Sumner, 2010). Salmela & Varho (2006) discuss the consumer passiveness in the green electricity market in Finland. Both individual and structural factors can influence a green electricity purchase. Lack of knowledge and trust, costs of switching, duties and routines in everyday life, price, and free rider problems could be barriers. The free rider problems in green electricity markets are explored in detail by Wiser & Pickle (1997). Pichert & Katsikopoulos (2008) explain the non-adoption with a kind of status quo bias. If grey electricity is offered as a default, few would switch to green electricity. In a German town, customers were asked to make a choice between slightly cheaper grey electricity, substantially more expensive super green electricity, and the status quo a default green alternative. Two months after the request to make a choice, 94% preferred the status quo. In another German town, everyone used green electricity. Eight years after a referendum decision, very few customers have made the switch to grey electricity. It is interesting to note that in Sweden, electricity customers are quite active. In 2010, around 11% of all domestic customers switched their electricity supplier and another 24% of consumers re-negotiated their contract with their current supplier (European Commission, 2011).

Actual adopters of green electricity have been profiled by a few studies. Attitudinal variables are powerful to explain adoption behavior. The effect of income is different according to types of programs (Kotchen & Moore, 2007). The number of environmental associations an individual participates in, economic factors (including WTP), knowledge, and environmental concern are correlated with adoption (Arkesteijn & Oerlemans, 2005). One may argue that people could make simultaneous decisions on membership and adoption. The interaction between these two decisions has not been addressed. Paper III fills this gap, in order to aid the understanding of motivations for households to switch to renewable electricity.

3.4 Participation in environmental organizations

In contrast with the abundance of research on other pro-environmental behaviors, less is known about the factors that influence participation in environmental organizations. Some studies focus on the money contributed and treat participation as a type of charitable donations (Hossain & Lamb, 2012; Israel, 2007; Wiepking, 2010). There is one study that examines environmental philanthropy involving both money and time (Greenspan *et al.*, 2012). Volunteering and donating to environmental organizations are separately used to measure philanthropy. Furthermore, both proclivity and intensity of volunteering and donating are respectively examined. Torgler *et al.* (2011) use the World Value Survey to investigate active participation in environmental organizations. It is found that individuals' active participation is not only related to socioeconomic factors but also related to political interests.

Most of the literature treats people who currently do not contribute in the same way, and these people are assumed to be affected by the same barriers for participation. This may provide inaccurate implications if this assumption does not hold. Paper IV relaxes this assumption and identifies different types of people who do not participate.

4 Data

To investigate determinants of the share of renewable energy in the energy mix, a panel data set from 1990 to 2010 for twenty-six OECD countries is constructed for paper I. The contribution of renewables to energy supply (CRES) is used as a relative indicator of development of renewable energy. According to what is suggested by previous literature, economic factors and policy factors are used as explanatory variables. Economic factors include GDP, energy consumption growth, energy import, and energy price. R&D, feed-in tariffs, and quota obligations are popular policy measures and their effectiveness is examined in the analysis.

Paper II and III are based on an OECD web survey on Environment Policy and Individual Behaviour Change (EPIC) which was implemented in 2007. This project attempts to provide implications for a design of more effective and efficient policies. It covers five areas where households exert particular environmental pressure: residential energy, water use, transport choices, food consumption, and waste recycling. The survey was conducted in ten countries: Australia, Canada, Czech Republic, France, South Korea, Norway, Sweden, Netherland, Italy, and Mexico. About one thousand respondents are represented in each country. Efforts are made to ensure the samples are representative across different age groups, gender, regions and socio-economic status.

Paper II elicits WTP for renewable electricity in six countries: Australia, Canada, Czech Republic, France, South Korea, and Norway. These six countries are selected because there is different culture, mix of energy policies, and climate across these countries. The variation allows for a comparison across countries that have not been possible before this study.

The first part of the questionnaire is about the standard background of respondents' socio-demographic characteristics. Questions were asked about their gender, age, education, employment status, and household composition.

Respondents were also asked to describe their current residences and membership in environmental organizations. The second part of the questionnaire concerns respondents' attitudes towards various environmental issues. Respondents were asked how much they are concerned about environmental problems. They were also asked to express their extent of agreement to some statements about the environment.

The energy section concerns household energy consumption, demand for renewable electricity and appliance investment. Respondents were asked about their WTP in terms of maximum percentage increase on the annual bill to use only renewable electricity[2]. And the amount of energy consumption is assumed constant. The way of asking the percentage value provides an opportunity for a comparison across countries, avoiding the problem of currency conversion. The answers to this question are interval censored, which implies that the exact value of a respondent' WTP is not directly indicated but the WTP can be known within a certain interval. If the percentage of choosing each particular interval is connected by a line, the resulting curve can be roughly interpreted as the demand curve (Johansson, 1993). A first look at the demand curve in the selected six countries is presented in Table 1. As expected, for each country, fewer respondents accept to pay the implied price with increase of the price.

Table 1. *Proportion of WTP*

Country	0	<5%	5%-15%	16%-30%	>30%	Don't know	Total
Australia	0.369	0.269	0.178	0.027	0.011	0.146	1
Canada	0.334	0.228	0.164	0.029	0.009	0.236	1
Czech Republic	0.297	0.271	0.185	0.023	0.009	0.215	1
France	0.432	0.263	0.113	0.018	0.010	0.164	1
Norway	0.427	0.174	0.189	0.034	0.016	0.160	1
South Korea	0.292	0.340	0.175	0.024	0.013	0.156	1

Respondents were also asked if they have taken special measures to buy renewable electricity. For those who have not, they were asked about the reason. Table 2 describes the data which is used in paper III.

[2] Lund (2007) discusses the perspective of converting an energy system into a 100% renewable energy system, and concludes that such development is possible.

Table 2. *Membership in environmental organizations and adoption of renewable electricity in Sweden*

	Non-member	Member	Total
Non-adopter	496	75	571
Adopter	99	37	136
Total	595	112	707

To investigate participation in environmental organizations in detail, the World Value Survey is employed, which provides information about membership using non-member, inactive member or active member. The World Value Survey is for investigation of political and socio-cultural change with representative national samples. Several waves have been conducted. The 2005-2006 wave is used in this study. Besides socio-demographic characteristics, respondents are also asked to express their attitudes towards the environment, including relative importance of the environment and economic growth, and level of environmental concern. Individual's attitudes towards other issues were also asked, such as confidence in environmental organizations, and importance of leisure time. Table 3 presents membership in Sweden, which shows that 11% of the respondents are members. By contrast, the OECD data suggest a little higher participation rate (16%).

Table 3. *Membership in Sweden*

Non-member	Inactive member	Active member
784	88	9

5 Method

Econometric techniques are used to investigate the renewable energy promotion from the supply side and the demand side. The rationale for the model selection is as follows.

5.1 Paper I

The panel data modeling approach is applied to investigate factors that affect the share of renewable energy in OECD countries. A two-way fixed effect model is employed. An inclusion of country effects and time effects controls for unobserved characteristics such as resource endowment and international events.

5.2 Paper II

The contingent valuation is widely used to elicit people's WTP for renewable electricity. The value of WTP for renewable electricity is not directly identified by the question asked, but it is collected in a format that indicates a range of values that contains the precise WTP. WTP can be considered a random variable C, and the continuous cumulative probability distribution function is:

$$F(c) = \Pr(C \leq c) \tag{1}$$

The objective of the contingent valuation study is to recover an estimate of the population distribution F with sample data from surveys. As an option, F can be assumed by some distribution functions. It is shown that the proportion of respondents willing to pay the implied price decreases as the price increases. This type of data is consistent with survival analysis framework. The survival here is defined with respect to the price instead of time. It can be interpreted that respondents "survive" the amount if they would pay that amount and "fail" that amount if they are not willing to pay it. In the survival analysis several parametric models are available to estimate WTP, including the exponential model, Weibull model, log-normal model, and log-logistic models.

The Weibull distribution is popular because it is flexible to a variety of positively skewed distributions (Weibull, 1951). So it is applied to the WTP curve with maximum-likelihood techniques. Mean WTP is the area bounded by the cumulative distribution function. The cumulative distribution function of the Weibull distribution with a shape parameter k >0 and a scale parameter λ>0 is given by:

$$F(x) = 1 - e^{-(x/\lambda)^k}, x \geq 0 \qquad (2)$$

Alternatively, F can be estimated using distribution-free methods which make no assumptions concerning the population distribution of the underlying WTP. One popular approach in contingent valuation studies is Turnbull estimator which is a self-consistent algorithm (Turnbull, 1974; Turnbull, 1976). Iterative numerical techniques are required.

5.3 Paper III

Although a rich set of variables is used to explain the adoption of renewable electricity, I notice that an independent variable, membership, could be correlated with some unobservable variables. If so, either a probit or logistic model likely yields a biased estimate. There are two common approaches to correct the omitted variable bias. One is the two-stage estimator, and the other is the maximum likelihood estimator. The latter approach is usually considered more efficient than the former (Greene, 1998). Because adoption and membership are both binary variables, the recursive bivariate probit model, which is estimated with maximum likelihood methods, is applied.

According to Maddala (1986), to guarantee the identification of a recursive bivariate probit model, at least one exogenous variable is required in the equation for the endogenous variable but not in the outcome equation. This exogenous variable is called an exclusion restriction or instrumental variable. It is required that the instrumental variable is closely correlated with the endogenous variable, but it does not directly influence the outcome variable. However, as Wilde (2000) shows, identification can be achieved even if the same exogenous variables appear in both equations as long as there is variation in the exogenous regressors. This is identification by function form. Recently more researchers point out that identification solely based on functional form in such models may be empirically fragile (Monfardini & Radice, 2008; Jones, 2007). The role of an exclusion restriction in model performance in various misspecifications of the error term is simulated by Meier (2013). When both the endogenous variable and the outcome variable have a low probability of occurring, as in our case, estimation in the presence of non-normal errors can be improved with an instrumental variable, even with a faulty instrumental variable. As a result, although it is not necessary for a theoretical identification, an exclusion restriction is imposed to relax the normal distribution assumption.

The decisions on adoption and membership can be made simultaneously. They are both binary variables, so there are four alternatives an individual could choose: non-member & non-adopter, member & non-adopter, non-member & adopter, and member & adopter. The multinomial probit model is applied to investigate the effect of various factors on the probability of choosing each alternative. Non-member & non-adoption is a popular alternative, so it is set as the base category. The coefficients estimated are interpreted as attraction of choosing each alternative compared with the base category.

5.4 Paper IV

Membership in an environmental organization is grouped into three categories. When the standard ordered probit model is employed, it is assumed that participation lies on a continuous scale across the membership status. The probit model treats all non-members as a homogenous group. The problem is that there may be two types of non-members: genuine non-members and current non-members. Genuine non-members are not interested in participation and they are unlikely to participate under any circumstances. Current non-members are interested in participation and they may participate in the future if some circumstances change.

The zero-inflated ordered probit (ZIOP) model is applied to reveal membership in environmental organizations. It combines a probit equation and an ordered probit equation as sequential stages of a decision: interest of participation and intensity of participation. With this model, it is assumed that intensity of participation in the second stage lies somewhere on a continuous scale, from zero to inactive participation, and to active participation. If an individual is not likely to participate, the person is considered to be a genuine non-member. If an individual is likely to participate, then a level of participation intensity (zero, inactive or active) is chosen. Zero intensity implies a current non-member, and it denotes that the respondent is interested in participation but the current level of intensity is zero. The model is illustrated by Figure 1.

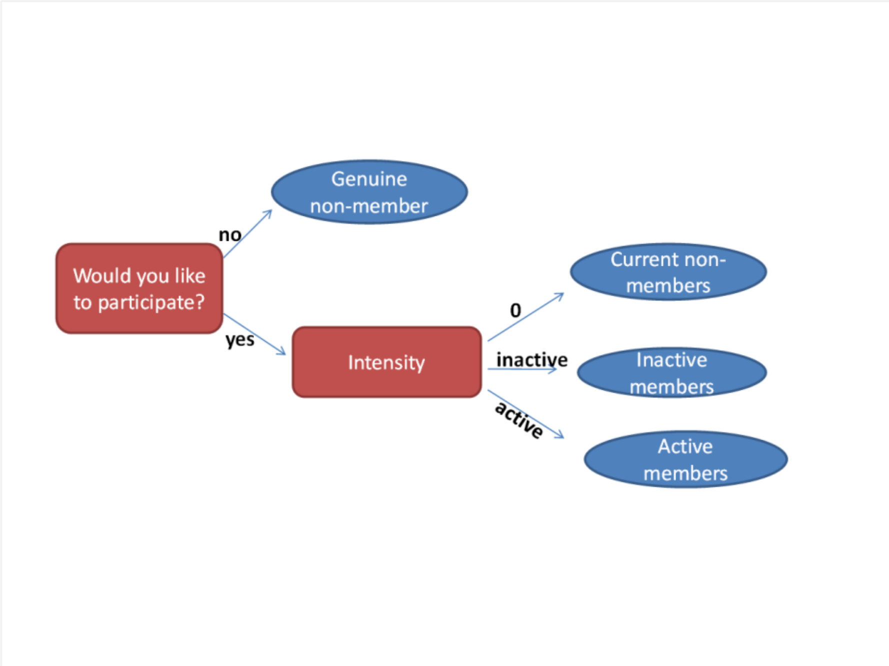

Figure 1. Modeling participation in environmental organizations

6 Summaries of appended papers

6.1 Paper I The share of renewable energy and policy support

Results of the fixed effect model show that R&D activities are positively correlated with the share of renewable energy. This is because R&D activities reduce the cost of technologies through innovations. The results also indicate that having a national, market-based policy instrument in place increases the share of renewable energy. However the individual implementation of feed-in tariffs or quota obligations is not found to have a statistically significant effect to increase the share of renewable energy. The results should be interpreted with the limitation in mind that feed-in tariffs and quota obligations are used mainly to support renewable electricity. Their individual effect is not significant enough to influence diffusion of renewable energy. The results also indicate that if energy consumption growth increases the share of renewable energy decreases. This is because currently it is still more popular to meet energy demand with conventional energy in a short time.

6.2 Paper II Residential demand for green electricity

This paper examines WTP for renewable electricity in the residential sector in six OECD countries. WTP is estimated using both parametric and non-parametric methods. The mean WTP estimated with the Turnbull approach and those from the Weibull model are consistent, in spite of slight differences. Within-country variation of WTP is found. The largest within-country variation is in France. The WTP of people in the Southwest (8.9% for Weibull model) is nearly twice of that in Norwest (4.8% for Weibull model).

This study also examines factors which may shift the demand curve. A respondent's entry decision is reflected by a positive WTP, and the motivating factors behind the entry decision are revealed using the logistic model.

Conditional on positive WTPs, with the Weibull specification, factors influencing the amount of WTP are examined. The results show that the entry decision and the amount of WTP are driven by a different set of factors. Environmental attitude/concern is consistently correlated with the entry decision. People with more environmental concern are more likely to express a positive WTP. For those who express a positive WTP, members of environmental organizations have a higher average WTP. Other factors that shift the demand curve are different across countries. Heating degree days (HDD) and cooling degree days (CDD) are used as proxies for the demand for energy needed to heat or cool a house. They are found negatively correlated with entry decision in Norway and the amount of WTP in South Korea. This implies that the more energy needed to heat or cool the residence, the less people are willing to pay for renewable electricity. But this effect is not significant for other countries.

6.3 Paper III What motivates households to adopt renewable electricity?

This paper investigates motivations of residential adoption of renewable electricity. If membership is expected to influence adoption, but not the other way round, males and people who strongly agree that individuals should pay for environmental policies are more likely to adopt renewable electricity.

Although different interactions between the two decisions are considered, the results are consistent. If the two decisions are considered to be affected by each other, it is found that the probability of choosing to be a non-member & adopter increases if an individual is a male, concerned with environmental issues, or an individual strongly agrees that people should pay for environmental policies. The probability of choosing to be a member & non-adopter increases if people are more concerned with environmental issues. The probability of choosing to be a member & adopter increases when people are environmentally concerned or they strongly agree with paying for environmental policies. Other factors do not play a role in explaining adoption of renewable electricity.

6.4 Paper IV Participation in environmental organizations: who and how?

First, this paper uses a conventional ordered probit model to model participation in environmental organizations. The result shows that household income is not correlated with people's participation in environmental organizations. When a two-stage decision process is assumed for the ZIOP model, it is interesting to find that income is found positively correlated with interest of participation and negatively correlated with intensity of participation. This suggests that the ordered probit model easily mixes the effect of factors in the two stages when there are a large proportion of zero observations.

The motivations in the two stages are not the same. Confidence in such organizations increases interest of participation, but confidence is not found correlated with intensity of participation. However, attitudes towards the environment play important roles in both stages. People who prefer the environment to economic growth are more likely to participate. People who are more concerned with the environment are more likely to contribute intensely. Another interesting finding is that among all the non-members, the proportion of current non-members increases with income level.

7 Conclusions and implications

The purpose of this thesis is to provide some guidance about how to effectively promote renewable energy from the supply and demand perspectives. The policy measures from both sides could function in parallel to effectively increase the share of renewable energy. Main findings and policy implications of the four appended papers can be summarized as follows:

From the supply side, most renewable energy comes from emerging technologies, and there is much potential to reduce generation costs. R&D has played an important role in increasing the share of renewable energy. This implies the importance of increasing government investment in R&D. While there is evidence that having a national, market-based policy instrument in place increases the share of renewable energy in a country, this study does not find evidence to prefer a quota or a tariff. The individual effect of feed-in tariff and quota obligations is not statistically significant. Keeping in mind that they are measured with dummy variables, a careful design of magnitude of feed-in tariffs or quotas is further needed when these instruments are adopted.

From the consumer demand side, it is found that people are not willing to pay much for a significant expansion of renewable energy. It is a few percentage points of the current electricity bill for all the countries examined. This result is consistent with the findings of previous comparable studies. It implies that it is still not easy to extract a significant price premium for renewable electricity.

An interesting finding is that a higher WTP does not necessarily correspond to a higher probability of adoption. So in order to promote renewable energy from the demand side, policies based on the studies for real markets could be more efficient. Expressing a positive WTP is correlated with people's income, education, and age in some countries, while the effect of these factors is not significant for adoption of renewable electricity in Sweden. It is found that males, members of environmental organizations, and people who strongly agree with paying for environmental policies are more likely to adopt renewable electricity. This implies that government efforts to highlight the benefits individuals receive from renewable energy could increase residential adoption of renewable electricity.

The analysis also suggests that people's attitudes towards the environment play important roles in both stages of participation in environmental organizations. Particular attention should be paid to people's environmental concern, which is also important to increase the demand of renewable energy via membership in environmental organizations.

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