DETERMINANTS OF INTERNATIONAL SOLAR PANEL ADOPTION

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Photograph of Nova Scotia Bay of Fundy by Annemarie van Hemmen

Table of contents

List of figures, tables and equations

Figures

Tables

Equations

Glossary of terms

bounded rationality: the economic theory that decisions are made by settling for a satisfactory option due to limitations in awareness, cognitive abilities and time rather than a full analysis

cognitive dissonance, theory of: the idea that people will attempt to reduce psychological discomfort from holding contradictory views by selectively choosing knowledge, opinions, beliefs and behaviours that are consistent

feed-in tariff: a monetary incentive provided for producing PV electricity that is paid at a rate per kWh somewhat higher than retail electricity rates

heuristics: psychological shortcuts that serve as "rules of thumb" for making decisions based on past experience, peer decisions and estimations

irradiance: a measure of the intensity of sunlight hitting a particular area

payback period: a measurement of how many years it takes to pay back an initial investment with future payments or savings

PV system: all components involved in installing an operational photovoltaic module

rational choice theory: the economic theory that consumers make decisions in order to maximize utility, taking all options into account

rational expectations theory: macroeconomic theory that on average consumers will make decisions which maximize utility

social proof: a type of conformity heuristic where uncertainty motivates consumers to base their decisions on the decisions of their peers

status quo bias: the tendency to choose the default option, which stems from heuristic decision making

utility: the economic term for happiness or satisfaction

utility maximizers: consumers who choose the option with the most net benefits or least net costs in terms of utility

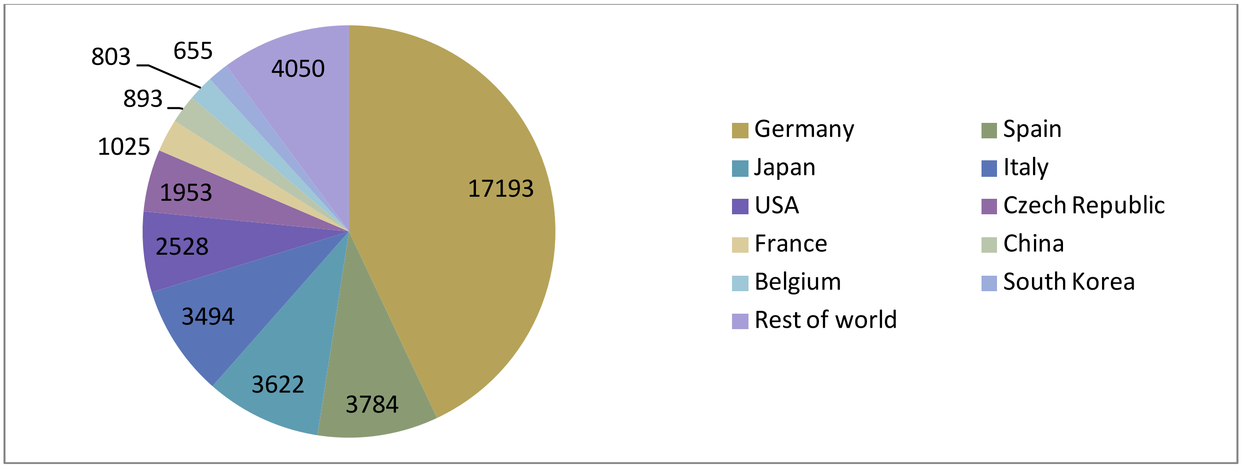
I. Introduction

This thesis looks at variations in solar panel adoption on an international scale. Solar markets in countries such as Germany, Japan and Italy have experienced large growth recently, while others have stayed stagnant. The following thesis examines whether this variability is due largely to differing monetary considerations or other non-monetary variables. First, it looks at the components that might influence the worthiness of the investment, such as PV system price, level of solar irradiance and various government incentives. It will then examine other factors which may have an impact on photovoltaic solar adoption. For example, it might be expected that a high level of oil reserves in a country would be indicative of slow solar adoption through the process of cognitive dissonance. Another non-monetary consideration may be awareness of the technology and its potential benefits generated through education of the population.

Background

Solar panels have demonstrated promise as a solution to existing energy problems. After the high initial cost of installation, they provide low cost and low maintenance power straight from a practically unlimited source of energy. However, the implementation of solar technology has been relatively slow, even within many high income areas that can afford the initial investment. Currently, there are several national markets which dominate solar uptake. Germany is the clear leader with 17,193 MW solar capacity as of 2010 (EPIA). Worldwide 2009 data shows that five countries account for more than three-quarters of cumulative installed solar panel capacity (Figure 1).

Figure 1. Leaders in cumulative installed solar panel capacity as of 2009 in MW



These striking differences in solar adoption by country form the basis for this research. On one hand, it is likely that there are monetary motivators at play. The best estimator of the monetary feasibility of solar panel adoption is probably payback period, a measurement of how many years it takes to pay back the initial investment of the PV system with savings in grid electricity cost reductions. A more specific monetary motivator would be solar irradiance, a measure of the strength of sunlight in a particular area. Higher solar irradiance is indicative of higher solar panel energy generation, greater reductions in grid electricity costs and therefore reduced payback periods.

However, not all of these monetary factors may be taken into account by consumers (as well as communities and governments) when considering solar adoption. Consider that Germany leads the world in solar adoption, but has below average levels of solar irradiance (EPIA, 2010). Discrepancies between the monetary conditions of solar adoption and the actual levels of implementation may be attributed to the idea that consumers do not always make purely "rational" decisions based on all attainable information[1]. While neoclassical models often assume that the rational choice theory holds for simplicity, this idea is being relaxed through the

[1] In economics, "rational" consumers are utility maximizers. The use of the term rational throughout this proposal will be based on this idea.

field of behavioural economics. For example, Herbert Simon introduced the model of bounded rationality, where decisions are made with limits in awareness, cognitive ability and time (Simon, 1982). Recently, a concept that has demonstrated relevance to ecological economics is cognitive dissonance, where people make decisions that fit within their worldview in order to reduce psychological discomfort (Festinger, 1957).

Behavioural economics also introduced the psychological concept of heuristics to explain consumer decisions. Heuristics are psychological shortcuts that serve as "rules of thumb" for making decisions (Kahneman & Tversky, 1974). They allow individuals to make educational guesses based on past experience, peer decisions and estimations. We all use heuristics in our everyday lives, since they take much less cognitive effort than a full rational analysis. These decision making tools are also relevant in an analysis on drivers of solar panel adoption since the framework must be conducive to not only the monetary drivers of solar adoption, but also the non-monetary cognitive factors.

Research problem

From existing economic literature, it appears that consumers may be deterred from making an investment in solar panel technology by a variety of monetary and non-monetary factors. The researcher conducted an observational study of international data to provide insight for two research questions, hereafter referred to as Q1 and Q2:

- Q1: Have successful national solar markets emerged from favourable solar economic conditions, where the adoption process is driven by an analysis of monetary feasibility?
- Q2: Are successful national solar markets also influenced by accommodation of non-monetary considerations such as bounded rationality, cognitive dissonance and various forms of heuristics?

Hypotheses

The following hypotheses were developed based on existing theoretical literature, the results of previous research and a number of informal interviews conducted by the researcher.

- H1: National solar adoption will exhibit mostly weak correlations with monetary factors.
    - System price will exhibit a weak negative correlation.
    - Mean traditional grid costs will exhibit a weak positive correlation.
    - Solar irradiance will exhibit a weak positive correlation.
    - Average income will have a exhibit weak positive correlation.
    - Payback period will exhibit a weak negative correlation.
    - Government incentives will exhibit a strong positive correlation.
- H2: The following theories are expected to have an influence on solar adoption, tested using demographic indicators:
    - Bounded rationality
    - Cognitive dissonance
    - Familiarity heuristic
    - Conformity and social proof
    - Delayed outcomes
    - Status quo bias

Significance

The stated research questions attempt to provide insight into why solar panels are not being implemented in so many parts of the world. This is worthwhile since renewable energy, and specifically solar energy, has demonstrated many long-term economic, social and environmental benefits.

An important implication of solar panel adoption would be the facilitation of a more sustainable economy (Dincer, 2000). A continuation of a fossil fuel economy will lead to increased energy costs as reserves become depleted. Estimates of depletion of these resources are placed at about 35 years for oil and gas, and 105 years for coal (Shafiee & Topal, 2009). However, energy costs for these fossil fuels will become prohibitively high well before their complete exhaustion. Alternatively, implementation of solar energy should fuel additional PV innovations, resulting in lower energy costs (Sagar & Van Der Zwaan, 2006). Identifying and subsequently reducing the barriers to adoption of to solar energy will facilitate this shift and put the global economy on track for reduced energy costs.

A shift towards solar energy would also result in social benefits in the form of decreased dependence on non-local sources of energy (Scheer, 2002). Since the sun shines everywhere, theoretically everyone would have access to their own power[2]. There would be interconnectedness in terms of grids, since solar energy storage is limited and the sun is not always shining everywhere. However, current international strife over energy that has taken the form of political struggles and even large-scale wars has the potential to be avoided with solar panel technology. This has implications for equality and reduces the likelihood of energy-related violence such as oil wars (Kaldor, 2007).

Finally, a shift towards solar energy would have many benefits for the environment. Current dependency on fossil fuels has resulted in many environmental concerns. A primary issue is emissions from combustion: CO_2 emissions contribute to climate change, SO_2 and NO_X emissions result in acidification of waterways and soils, and particulate emissions raise health concerns for humans and other organisms. There is also environmental degradation associated with the extraction and transportation of fossil fuels. There are domestic examples of this in the oil sands in Canada, as well as international examples such as the recent BP oil spill in the Gulf of Mexico (Gosselin et al 2010, Hagerty & Ramseur 2010).

[2] This is dependent on further advances in PV technology, since solar panels are not economically viable in every environment with current levels of efficiency.

It is important to note here that solar panels also have some environmental concerns associated with their life cycle. Their production requires heavy metals, whose mining has been known to result in serious environmental degradation (Alsema & De Wild-Scholten, 2006). In addition, the transport of the materials and manufacturing of the panels produce emissions since they are currently being made using machinery run on fossil fuels (Alsema et al, 2008). In the case of a serious shift toward solar energy, the latter problem would be eliminated. The former problem poses serious limitations to solar energy though, and a significant shift towards solar would require either a substitute for the metal materials or that environmental degradation from their production is mediated. It would also be dependent on the existence of enough heavy metal reserves to produce solar panels on a large and economically viable scale. This has yet to be determined, even with proper recycling (Fthenakis 2009).

Contribution

The research has both practical and theoretical contributions to the field of environmental science. In practical terms, increased knowledge of solar panel adoption decisions would allow solar panel companies, governments and other solar proponents to cater marketing in order to address the concerns of consumers. In addition, governments may consider new legislation or incentive programs that would facilitate more solar panel adoption or consider adjustments to those that are already in place. This would result in the increased economic, social and environmental benefits associated with solar panel technology discussed above. In addition, the research provides theoretical contributions by supplying empirical evidence to back up or call into question current consumer models, particularly with regards to green technology adoption.

Structure of the report

The remainder of this report will consist of literature review, methods, results & analysis, limitations, conclusions, references and a number of appendices. The literature review provides further information on solar markets, behavioural economics and recent studies, and provides context for the research. The methods section will brief the reader on the statistical methods employed and the rationale behind their use. Results will be primarily graphical in nature, with explanation guiding the reader through the process in the same basic order as the procedure laid out in the methods section. The researcher will then discuss limitations of the study, focusing on those created by the statistical tools used and a number of assumptions that were made. Finally, conclusions will provide summary of the results, their implications for policy and how future research may build upon this study. The references section includes scholarly sources, but a full list of data sources is found in Appendix A. Several other appendices with supplementary information are also provided and are referenced throughout the report.

II. Literature Review

There are a number of fields that are relevant to the research conducted. Initially, it is useful to review existing literature surrounding national solar panel markets. There are several international organizations responsible for accumulating and analyzing information about national solar markets that are helpful in this regard, as well as national reports developed by federal governments. Also relevant is the wide field of behavioural economics, which may explain the non-economic factors involved in solar panel adoption. Finally, a number of previous studies have been conducted to determine drivers of solar uptake at a national or provincial level that provide a good base for the research in terms of hypothesized monetary and non-monetary factors.

Solar markets

Solar markets in the context of this report include four main varieties of photovoltaic power (IEA 2009). Other types of solar power such as solar water heaters and passive solar systems also exist, but are excluded from this study since their markets differ so significantly from that of PV. The types of PV applications included in the theoretical framework and data of this report include the following:

1. Domestic off-grid PV (household installations typically around 1 kW)
2. Commercial off-grid (typically low W requirements such as highway lighting)
3. Distributed grid-connected PV (installations on buildings or premises where energy goes to the customer and/or electricity network)
4. Centralized grid-connected PV (high kW power stations, PV farms)

The basic distinction between grid-connected PV and off-grid PV is an important one. When a system is grid-connected, it is able to feed surplus energy that is not used at the location back into the electricity grid to be used elsewhere. Most developed countries have systems such as net metering or net billing where the energy that is fed back is kept track of and paid to the PV owner at a certain price per kilowatt hour (kWh) generated. This thesis assumes that the price paid is equal to the traditional grid electricity costs of the region unless a feed-in tariff or other non-fixed subsidy is in place.

The PV solar market has some relatively straightforward economic components that influence uptake, such as the income of consumers. If a country has a large number of citizens with available cash to buy a solar panel system, it would make sense that solar panel adoption would be higher there than in a relatively poor country. It will also be influenced not only by the domestic price of the module, but by the full PV system price. This is important since a potential buyer is likely to consider all of the associated initial costs of solar adoption and not just the price of the PV module itself. In the case of a grid-connected installation:

"PV system" = module(s) + mounting + inverters + control components

For an off-grid installation, storage batteries are also required (EIA, 2009). Although the typical lifespan of a solar panel is 40 years, it may be shorter for the various associated expenses, which should be kept in mind as payback period is discussed.

Payback period is an integral part of the solar PV market. This value represents the number of years it takes for the initial costs of the PV system to be fully paid back through savings in electricity costs. It incorporates the variables of system price, traditional grid electricity costs and solar irradiance, as well as a discount rate. The discount rate essentially makes future savings count for less in order to account for the economic concept that a dollar today is worth more than a dollar received tomorrow[3].

Many different types of discount rates may be used for generating payback periods. The market discount rate is useful since it represents the strict monetary amount one could be expected to make from investing a dollar in the free market rather than spending it (on a solar panel). Different discount rates are often used in cost-benefit analyses for projects that benefit the public good in order to account for the benefits that that are not quantified in the market through prices, also called positive externalities.

There are also many different forms of governmental incentives that may be used to reduce payback periods and therefore stimulate solar adoption. Notes on the approaches taken by the various countries examined in this report are provided in Appendix B. The table below summarizes the most common forms of programs that have been utilized in solar PV markets thus far (Table 1).

Type of incentive	*Description*
Enhanced feed-in tariff	explicit monetary reward provided for producing PV electricity paid (usually by the utility company) at a rate per kWh somewhat higher than retail elec. rates
Capital subsidies	direct financial subsidies aimed at tackling the up-front cost barrier, either for specific equipment or total installed PV system cost
PV-specific green electricity schemes	allows customers to purchase green electricity based on PV electricity from the electricity utility, usually at a premium price
PV requirement in RPS	a mandated requirement in a Renewable Portfolio Standard (RPS) that the electricity utility source a portion of their electricity supplies from PV
Income tax credits	allows some or all expenses associated with PV installation to be deducted from taxable income streams
Net metering	the system owner receives retail value for excess electricity fed into the grid, as recorded by a bi-directional electricity meter and netted over the billing period
Net billing	the electricity taken from the grid and electricity fed into the grid are tracked separately, and electricity fed into the grid is valued at a given price
Sustainable building requirements	requirements on new building developments where PV may be included as an option for reducing the energy footprint or specifically mandated as an inclusion

Table 1. Government solar programs, modified from IEA PVPS 2009 Trend Report

[3] This is based on the idea that I could go to the bank with a dollar today, invest it and have more than one dollar tomorrow due to the power of interest. This concept is one of the pillars of economics and of finance.

These programs are put in place not only to internalize the external benefits of solar panels, but also in hopes that greater market stimulation can drive down prices, encourage solar innovations and stimulate increases in PV efficiency. The end goal of government solar incentive programs is to reach grid parity, where the cost of solar energy is equivalent to traditional grid costs and PV reaches profitability without government intervention. Recall that the typical lifespan of a solar panel is 40 years. Therefore, grid parity would be reached when the payback period without government incentives is equal to 40 years as well. Solar panels would become a profitable investment when the payback period is less than 40 years.

Behavioural economics

Behavioural economics is a relatively new field but has accumulated information at a rapid pace, drawing heavily from psychology and neuroscience. Only the most pervasive and relevant contributors will be examined below, with emphasis on the origins of the field as well as the theories explicitly mentioned in the second research question. A discussion of the time-dependent factors that may influence solar adoption but are beyond the scope of this research are provided in Appendix C[4].

In economics, assumptions of consumer behaviour are necessary in order to model the actions and purchasing habits of large populations. These assumptions have evolved over time. Some classical models of the 1800s involved imperfect decision making, but had limited attempts at quantifying it. This was followed by the neoclassical economic movement, which focused on objective and testable questions. Due to the nature of decision making, which is

[4] While time-dependent factors are undoubtedly an important influencer of solar panel adoption through the power of inertia, this study has taken a cross-sectional view to examine differences in national approaches. Harnessing inertia will be imperative to reach grid parity for many countries in the future, but this thesis is more concerned with how to reach the point where inertia will take over in the first place.

often messy and unpredictable, economists tended to make the assumption that on average consumers will make “rational” decisions.

Rational decisions of the neoclassical movement were based on utility maximization, where the option chosen provides the most net benefits (Simon 1986). Consumers may individually err due to uncertainty or imperfect information, but since these elements are determined through chance, opposing choices will occur with the same frequency and the average outcome will be the correct, or most beneficial, outcome (Muth 1961). Rational decision models presume that there is no systematic bias, where wrong decisions will occur repeatedly in a certain direction. Examples of rational assumptions of this time include rational choice theory on a microeconomics scale and rational expectations theory for macroeconomics (Becker 1976, Muth 1961).

In the late 1960s, economists started to point out how primitive the behavioural assumptions of neoclassical models were (Akerlof 2001). For example, limitations on free time would dictate that consumers often make decisions based on only rough estimates of the true options. With these types of objections came the birth of behavioural economics. This field attempts to reflect actual decisions that consumers make by drawing on existing information about decision making that comes from psychology and more recently from neuroscience. The work described below highlights famous contributions from behavioural economics that may be applicable to solar adoption and this thesis.

One of the first and most influential modifications of rational decision making is the theory of bounded rationality, introduced by Herbert A. Simon (1982). Simon proposed that economic models needed to widen the scope of rationality to include psychological concepts. He also introduced the keywords satisficing and approximate optimizing, which reflect the idea that consumers make choices when a satisfactory option is found, rather than completing a full analysis of all options (Simon, 1972). Specifically, the theory of bounded rationality attempts to include limitations on awareness, cognitive abilities and time. These limitations may certainly be applicable to solar panel adoption – the nature of the decision to adopt requires high levels of all three of the listed constraints. Cognitive abilities within this thesis are assumed to be a constant for all countries. However, levels of awareness and free time are both explored through proxy variables. Countries with either naturally higher levels of awareness and free time, or alternatively countries that develop programs to minimize these constraints on solar adoption, should be expected to have higher levels of adoption.

Another relevant factor to explain varying solar panel adoption may be Leon Festinger's theory of cognitive dissonance (1962). This psychological tool is used to internally justify making the "incorrect" choice. The concept entails the reduction of mental discomfort (dissonance) about choosing the non-optimal option by distorting facts and analysis to fit the decision made. In Festinger's famous example, a smoker may reduce his psychological discomfort about smoking by convincing himself that the negative health effects of smoking are overblown, or that quitting smoking would result in weight gain that would be equally as unhealthy (1957, p. 5-6).

This concept has been used increasingly in behavioural and ecological economics, and particularly with regard to acceptance of climate change (Hulme 2009). Those who have the most to lose by adopting environmental friendly practices to address climate change are likely to reject the scientific evidence of climate change in order to reduce the dissonance of continuing environmentally damaging activities. This may be applicable to solar panel adoption if a country has CO_2 intensive industries or lifestyles, or high levels of oil reserves. In this case, it may be psychologically easier to ignore environmentally friendly products such as PV that might cause them to confront environmental sins in other aspects of their lives. Cognitive dissonance here has its roots in the idea that people like to think of themselves as "good" or moral – therefore, they must convince themselves that climate change is not anthropocentric in order to maintain their positive self-image despite continuing activities that damage the environment.

Cognitive dissonance may also be thought of in terms of social identity. Rather than altering their whole worldview from the addition of new knowledge, people are likely to selectively choose situations and information that fit with their general perspective on things (Festinger 1957, p. 3). This reduces dissonance generated from having clashing opinions on various issues. Therefore, just as a country with environmentally damaging practices may convince themselves that solar adoption is not worthwhile, a country that associates themselves with environmental integrity or the natural world may be more likely to adopt solar. Similarly, those countries that value social equality may experience higher solar panel adoption due to the social implications of solar discussed in the Significance section of the Introduction above.

Another significant concept in behavioural economics is heuristics. The application of these decision making tools to economics work was started by Daniel Kahneman and Amos Tversky in 1974 and much further work has been done since then. Heuristics are especially useful in situations where the choice is not obvious (Kahneman 2003). Where uncertainty or complexity exists, rational choice theory would assume that consumers would take the time to make fully informed decisions by researching the options thoroughly and thinking deeply about the possible outcomes and their probability. In reality this would represent a huge cost in terms of cognitive effort. Instead, consumers often employ shortcuts called heuristics or "rules of thumb". These decision making techniques are based on educational guesses and past experiences, and require much less cognitive effort for a decision (Tversky & Kahneman 1974).

In the context of solar panel adoption, the use of heuristics means that households are unlikely to perform an actual cost-benefit analysis of installing solar panels on their home. To save cognitive energy and time, consumers may reject solar panels by associating them with costly environmental measures or overly complex technology. Alternatively, a rule of thumb for decision making may be that items on sale are always a good purchase – as a result, consumers may be willing to adopt solar panels in excess if government incentives are available and advertised.

The familiarity heuristic may be applicable with solar panel adoption. Generally, products or technologies that are more familiar to the consumer are more likely to be adopted. The reason for this stems from another heuristic developed by Kahneman and Tversky called the availability heuristic, which states that concepts that are more easily available to the mind tend to get inflated weightings in terms of perceived frequency and importance (1974). Therefore, we might expect those that are more familiar with scientific technology, or technology in general, to be more likely to consider solar adoption.

The heuristic called social proof may also influence solar panel adoption, which comes from the basic concept of conformity. Social proof occurs when an uncertain consumer bases his decisions on the choices made by others around him by assuming that others have better knowledge of the various options. Social proof and conformity are reinforced through exposure (see Appendix C). Solar exposure may be generated by density of installations or alternatively by high-profile installations. For example, US President Barack Obama has committed to putting solar panels on the White House, which may have considerable ripple effects (Executive

Office of the President, 2010). This fits into Rogers's idea of community leaders having an imperative influence on the diffusion of new technology (Rogers 2003).

Another concept stemming from heuristics that dominates in decisions with uncertainty is the status quo bias (Samuelson & Zeckhauser, 1988). When people are unsure of the payoffs of various options and do not want to put effort into researching them, they tend to accept the default. This often happens whether or not it is the optimal outcome. A very small scale example of status quo bias involves watching television. Many people will continue to watch a particular station after their program ends rather than switching the channel simply because of the cognitive effort associated with surfing channels. It is likely that the viewer would be able to find a preferable show; however, a surprising number of people subscribe what Sunstein and Thaler call the "yeah, whatever" heuristic (2009, p. 35). Status quo bias also relates back to the time limitations of bounded rationality, since the consumer tends toward the option which requires less of a time commitment.

The status quo heuristic has implications for solar panel adoption since switching from the default grid power to solar panels involves much more cognitive effort than simply switching a television channel. If research finds that this factor is a significant influence for solar panel adoption, governments may propose legislation that makes solar panel installation the default for new houses, rather than a more extreme mandatory process. In this way, the public would still be given the option of energy sources, but the cognitive effort involved in securing solar panels for their house would be dramatically reduced.

Delayed outcomes may also play a significant role in the adoption or rejection of solar panel technology. The most obvious example of this type of "irrational" behaviour is obesity. While overweight individuals know that excessive eating is not in their self-interest, they often discount their future health in exchange for immediate satisfaction (Loewenstein, 1996). The same can be said for smoking, lack of exercise and procrastination in general. In the case of solar panels this may be applicable since the switch involves a very costly initial investment in terms of money and time, followed by future gains well into the future[5].

Solar adoption studies

Previous studies on solar panel adoption in relation to behavioural economics and more general international scholarly studies on solar markets were also drawn on throughout this research. There are a number of microeconomic studies that were used predominantly in order to give insight on perceived barriers. The macroeconomics ones were useful in giving insight on policy barriers and the influence of the supply side.

Past microeconomic studies often provided questionnaires to solar panel adopters and non-adopters within a community to better understand the motivations behind their choices (Bollinger & Gillingham, 2010; Claudy et al, 2010; Faiers, 2009; Jagar, 2006; Kinnear & Labay, 1981; Nagamatsu et al, 2008; Rothfield, 2010; Sherk & Parker, 2010). For example, Duncan Labay and Thomas Kinnear (1981) drew heavily on the diffusion of innovations theory laid out by Rogers, which provides a great starting point for relevant heuristics. However, their spatial scope was limited to Maine, which means that the study could not aid the researcher with broader social influences and perceptions, as well as evaluative feedback on the influence of government legislation regarding solar technology since this element was consistent throughout the surveyed population. A similar story could be told for Faiers's study in the United Kingdom, Sherk and Parker's study in Ontario and Jager's study in the Netherlands.

[5] The reader may also choose to think of delayed outcomes as a "rational" factor by assuming a high discount rate on future payments. This discount rate would have to include the market discount rate as well as a premium for the preference for immediate satisfaction.

Four studies were found that performed a comparison of successful and unsuccessful national markets for solar panels (Balaguer & Marinova, 2009; Beise, 2004; Foxon et al, 2008; Shum & Watanabe, 2007). Collectively, these studies examined the solar markets of Japan, Germany, the United States, the United Kingdom, China and Australia, although each individual study looked at either two or three countries. These studies provided excellent theories for causes of different rates of adoption. However, since these studies used limited statistical data and analysis, the proposed research has the opportunity to provide extensive supplementary evidence to build upon their work.

Essentially, what is missing is an effort to compare both the natural and government-induced atmospheres towards solar panels of a variety of countries with both successful and unsuccessful solar panel markets through the use of existing datasets. Using statistical methods with these datasets can provide insight, with help from concepts in behavioural economics, on the drivers of solar panel adoption. This in turn may have implications for how government policy may be framed to best facilitate further solar adoption. Since the research for this thesis is looking at large national markets it will be able to capture factors that studies on smaller communities have not be able to, such as varying levels of irradiance, national social factors and government incentives.

III. Methods

The research was conducted in two main phases. In the first phase, monetary considerations were evaluated through calculation of relevant statistics and generation of correlation coefficients against national levels of solar panel adoption. In the second phase, non-monetary factors were considered through correlations with representative indicators.

Data

The majority of solar-related data was taken from two international agencies dedicated to providing solar information: the International Energy Agency Photovoltaic Power Systems Programme (IEA PVPS) and the European Photovoltaic Industry Association (EPIA). These organizations obtain their information from annual reports filed by federal governmental agencies, which were also consulted. Solar-related data taken from IEA and EPIA reports and datasets includes solar capacity adopted in 2009, cumulative installed solar capacity, solar system price and various federal government incentive programs. Cumulative installed solar capacity, the main variable used for solar adoption, was available for a total of 35 countries.

Non-solar data was pulled primarily from the World Bank indicators dataset and CIA World Factbook. This consisted mainly of demographic variables used for the second research question, but also included relevant statistics needed for the first research question such as population data used to obtain solar adoption per capita.

Other data sources include the OECD, UNFCC and US EIA. A full listing of the sources for data is available in Appendix A. In the event that the researcher made estimates or assumptions for selected data, notations are made in the results. This was often done when data had limitations in accuracy due to restricted knowledge. On some occasions the researcher only had access to data for selected countries. Sample sizes for the data are provided in Appendix A.

Measurements

The main measurement used to gauge national solar adoption was the natural log of 2009 cumulative photovoltaic solar capacity in watts per capita. The variable was divided by national population to obtain per capita data in order to normalize for population. Per capita data was used since the researcher is looking for saturated solar markets as opposed to its pure size. For example, the USA appears to be a leader in solar adoption from cumulative capacity, but when normalized for its large population it does not fare as well. The data was also transformed by logging the dependent variable. This was done because it appears that a small change in an independent variable (such as system price) might lead to an exponential increase in adoption. This phenomenon may be attributed to diffusions of innovations theory – see Appendix C.

In some cases, the researcher also introduced the natural log of photovoltaic solar capacity installed in 2009 in watts per capita as a measurement of solar adoption. This measurement was used when correlating against variables that are expected to be volatile from year to year. For example, governmental policies may change dramatically due to market conditions and new administrations. By limiting both solar uptake and government policies to 2009 data, yearly volatility can be controlled for[6]. These variables were still run against cumulative capacity as well for comparison's sake. For an illustrative example of the significance of using different measurements of solar adoption, consult Figure 13, Appendix D.

Also of note is that the researcher used GDP per capita as a proxy variable for average income. This is a common practice in econometrics, but does introduce some bias since it does not perfectly reflect average household income, and because, like any average, it will not give insight about the distribution of income (Rankaduwa 2011). To examine income distribution

[6] Note that 2009 data was used instead of more recent (and interesting) 2010 data since the newer data was partial and less accurate, and the researcher wished to have greater confidence in the results.

influences the researcher introduced the Gini index, a well-known measurement of national inequality, in the non-monetary considerations.

For the second research question, many of the factors needed proxy variables. It is useful to remember that the relationship between solar adoption and the non-monetary components is limited by the accuracy of the proxy. For example, the proportion of the population that has internet access is one of the proxies used for awareness limitations. This is probably a reasonable proxy variable to use as a substitute for non-quantifiable awareness, but does not take into account people who may read about solar in the newspaper, see an advertisement on television, etc.

Phase 1: monetary considerations

Six main monetary considerations were highlighted in the first research question: system price, solar irradiance, traditional grid electricity price, average income, payback period and government incentives. Direct data was available for irradiance, system price, income and grid electricity price, so they were run against national solar adoption in Microsoft Excel using the following standard equation for Pearson correlation coefficients.

Equation 1. Correlation coefficient, r

$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}}$$

The values of r range from 1 to -1, where 1 represents a perfect positive correlation, -1 represents a perfect negative correlation and 0 represents no correlation. This thesis considers absolute values greater than 0.6 to be relatively strong correlations and those below 0.4 to be relatively weak.

Average payback period is a measurement of the irradiance, system price and grid electricity price variables together. The researcher decided on two main equations for the purposes of this research, as follows:

Equation 2. Payback period without discounting

$$\mathrm{PP} = \frac{\mathrm{P_s}}{\mathrm{E} * \mathrm{I} * 0.001}$$

Equation 3. Payback period with discounting

$$\mathrm{PP} = \mathrm{when} - (\mathrm{P_s}) + \frac{\mathrm{E}}{(1+r)^1} + \frac{\mathrm{E}}{(1+r)^2} + \cdots \frac{\mathrm{E}}{(1+r)^n} = 0$$

Where:

PP = payback period in years
P_s= average system price in US$/Wp installed
E = grid electricity price in US$/kWh generated
I = average irradiance in kWh generated / kWp installed
r = discount factor
n = number of years = PP = payback period

Equation 2 is a general modification from the National Renewable Energy Laboratory of the US Department of Energy used to generate payback periods by state (NREL 2010). This equation is a good proxy for simple estimates of national payback period. However, since it does not take into account a discount factor it will not provide an estimate for reaching grid parity[7].

Alternatively, Equation 3 does include a discount rate, r. The value chosen for r in Equation 3 will have a substantial influence on the results of the payback equation. The researcher used r = 0.04 for the results given below. This represents a relatively low discount rate and was chosen in order to accommodate external benefits from solar adoption (Cline 1999). Both Equations 2 and 3 assume that operation and maintenance costs will be negligible. They

[7] However, some economists argue that environmental investments should have discount rates very close to zero to order to incorporate the utility gained by future generations from a cleaner planet (Portney & Weyant 1999). Additionally, it may be argued that market discount rates may be offset by increasing grid electricity prices.

also assume that surplus electricity may be sold back to the power supplier at traditional grid electricity costs.

The final monetary consideration for the first research question involves examining differing government incentives. As described in the first section of the literature review, there are many different ways that a government might incentivize solar panels. These incentives are also likely to differ depending on panel size, type and geographic location. To streamline these, the main indicator of government incentives used was a dummy variable.

The dummy variable was limited to two general categories: fixed monetary incentives (direct capital subsidies) and monetary incentives dependent on electricity generation (feed-in tariffs[8]). A value of 1 was given if direct subsidies were present in 2009 and 0 if they were not. 1 was added to this value if a FiT scheme was present in 2009 and 0 if it was not. Therefore, a maximum value of 2 could be reached if the government offered both a FiT and direct subsidies. The researcher recognizes that this methodology has limitations since, for example, a strong FiT is likely to have more influence on adoption than a weak one.

Direct quantification of the various FiT and subsidy schemes was attempted. However, limitations on available information meant that this data was compromised in terms of accuracy. In large part this was due to a number of governments exercising few national programs but many provincial or even municipal ones that would be impossible to fully quantify and weight for 35 countries due to time limitations. Countries may also vary considerably in the details of their program. For example, Germany has a sophisticated corridor system for their FiT program that adjusts the future payments received to stay within a certain "corridor" of national solar adoption. For an example of direct subsidies, it may be useful to consider Australia where

[8] FiTs are not the only non-fixed monetary incentives based on electricity generated, but are the most widespread and are typically much stronger incentives than the alternatives.

subsidies for residential installations are only available for households with income less than 100,000 AUS dollars.

However, the researcher determined that monetary incentives were of utmost importance to payback period and must therefore be presented in some capacity. For FiTs, the researcher calculated a simple average based on the various national incentives per kWh for differing panel sizes and types. This value was then used in place of the grid electricity cost E in Equation 2. For direct subsidies, the researcher assumed a 1 kW system and subtracted the national direct subsidies per watt that would be received from the system price per watt variable P_s.

Underestimation will occur with the new generated payback period since FiT programs are often offered to the consumer for a fixed number of years that is generally less than the lifespan of the panel. Additionally, it assumes that energy directly used by the consumer will receive the FiT value in future paybacks rather than the grid electricity value, which is often not the case. Overestimation of payback period will simultaneously occur since provincial and municipal programs are not being taken into account.

The researcher also attempted to quantify the total government incentives based on national expenditure on PV expenditure. This was calculated in two ways. The first included the country's entire public budget devoted to PV technology, including research and development subsidies. The second included all demand-side incentive schemes, so excluded R&D but added FiT schemes that are funded through utility companies rather than governments. Unfortunately, this data was only found for ten countries so the dummy variable remains the dominant measurement for government incentives.

Phase 2: non-monetary considerations

For non-monetary considerations, the researcher initially generated correlation coefficients on many variables, and edited the list after each round of results. Subsequent to initial testing, the researcher focused on the proxies listed in Table 2 as indicators for the examined non-monetary theories laid out in the second research question. These proxies are the focus of the Results section, but the calculations for all tested indicators are provided in Figure 11 of Appendix D. Also note that the natural log of cumulative solar capacity per capita was used here since the non-monetary variables are not as volatile as government incentives and other monetary considerations.

Non-economic consideration	*Proxy variable(s)*
Bounded rationality, awareness	Average years of education, internet access per capita
Bounded rationality, time	Average labour hours worked yearly
Cognitive dissonance	Oil reserves per capita, CO_2 emissions per capita, solar labour places per capita, environmental performance index, Gini index
Familiarity heuristic	Scientific and/or technical articles published yearly, high tech exports as a percentage of total manufactured exports
Conformity and social proof	Population density, urban population as a percentage of total population
Delayed outcomes	Public debt as a percentage of GDP, compared influence of initial price and future returns
Status quo bias	Qualitative government policies

Table 2. Proxy variables used for non-economic considerations

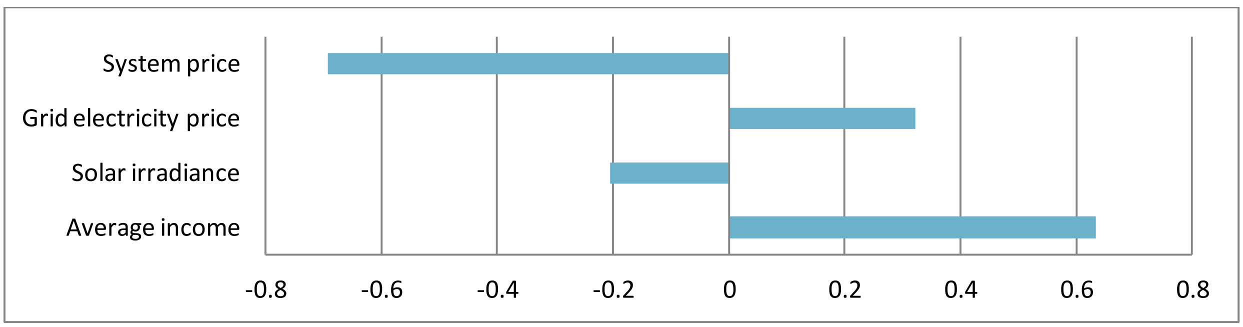
IV. Results and analysis

The results have been organized chronologically according to the methods, reflecting the first and second research questions. Use of tables and figures has been limited to the most relevant information; additional tables and figures may be found in Appendix D.

Preliminary monetary considerations

The following figure shows the generated correlation coefficients for solar adoption against the data that was retrieved directly from international sources, which included solar irradiance, system price, traditional grid electricity price and GDP per capita as a proxy variable for average income.

Figure 2. Correlation coefficients for selected economic variables with ln of cumulative solar capacity per capita



Of the four variables, three reflect the expected direction of the relationship. Income and grid electricity prices have a positive relationship with solar adoption. This means that if a country's average income or grid electricity price increases, so should solar uptake. System price has a negative relationship with solar adoption, which was also expected. If it costs less to install a system, solar adoption should be higher (and vice versa). Keep in mind that the system price used here does not take into account various subsidies and rebates that the government may offer, so it may not be the actual cost paid. However, direct subsidies are often in the form of a percentage of the costs of the system which would not change the relationship between price and solar adoption.

Solar irradiance does not exhibit the expected relationship from a rational consumer. Higher levels of irradiance (stronger sunlight) should make a consumer more interested in buying solar panels since it would give them higher payoffs in the future. Therefore, solar adoption and irradiance should have a positive relationship. However, in the above figure there is a negative relationship. This result is probably due to differences in GDP – countries nearer to the equator such as India, Malaysia and Mexico will have higher irradiance (2100, 2100, 2150 respectively) but also tend to have low incomes ($1192, $7030, $8143 respectively) which would have an influence on solar adoption. As a result, the influence of solar irradiance can probably not be accurately interpreted through the statistic generated above.

The strength of the relationships gives some important insight about monetary considerations. System price has the strongest correlation with solar adoption of all of the preliminary economic considerations (-0.69). This implies that people are either unwilling or unable to pay a high initial cost for a PV system. The fact that system price has a much closer relationship with solar adoption than grid electricity price (0.32) also tells us that people may not look very far into the future when considering costs. Average income was also a relatively strong correlation (0.63), which may indicate that the initial high cost of solar may be an important barrier to adoption.

Payback period

The next step to consider was payback period using Equations 2 and 3. The rationale for using these formulas may be found in the Methods section of this report.

Figure 3. Average payback period without government incentives using Equation 2

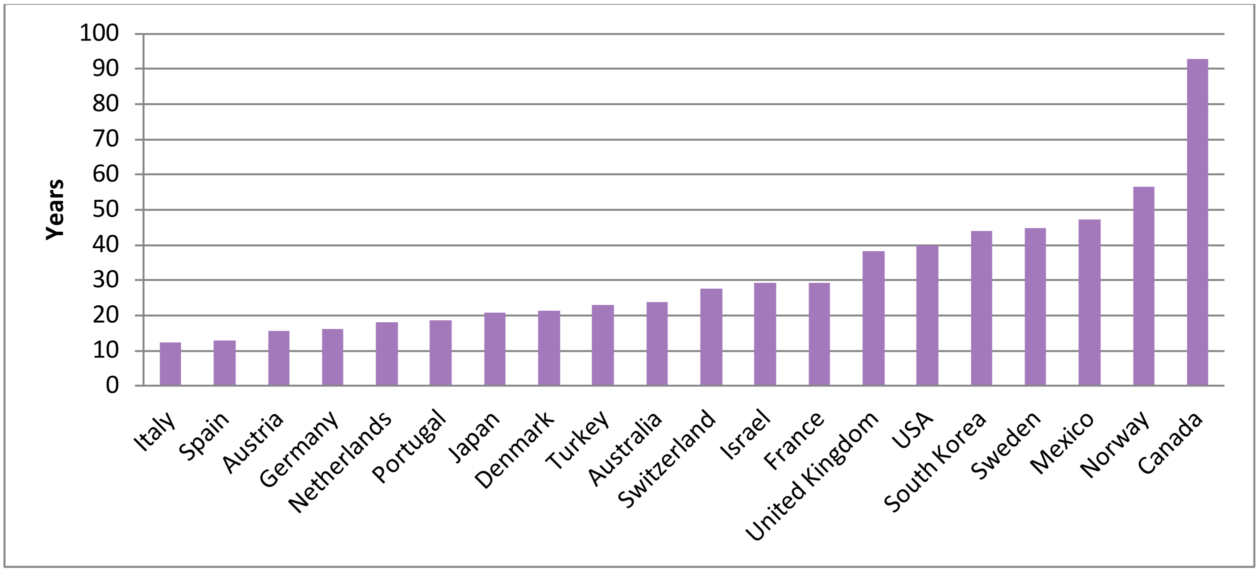
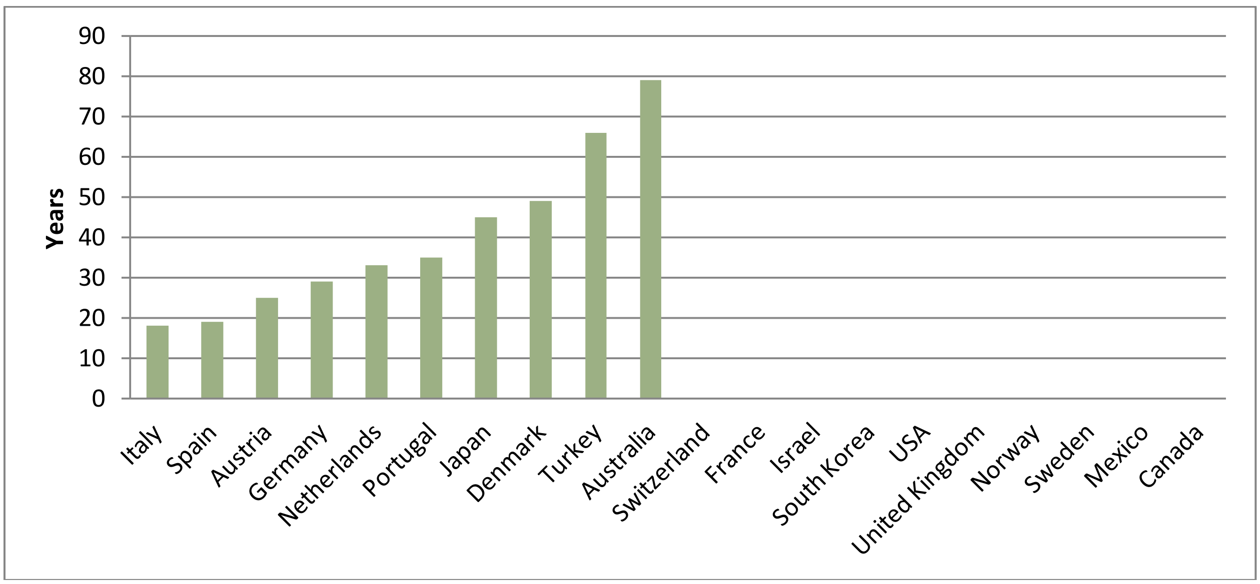


Figure 3 uses Equation 2 to generate payback periods without government incentives or discounting. Keep in mind that the above values do not indicate when solar will reach grid parity since the future energy cost savings have not been discounted by the discount rate. Since these values have not been discounted, Equation 1 will give overly optimistic estimations. However, in the case that external utility from solar adoption offsets the discount rate, this would be an accurate representation of the years for a net utility return of zero. Additionally, discount rates may be offset by increasing electricity prices due to fossil fuel scarcity. If this is the case, solar panels would be a good investment for all countries with payback periods less than 40 years, which is the typical lifespan of a solar panel. This is evident in many of the above countries.

This measure is an effective simple proxy for comparing which countries have naturally good conditions for solar adoption and therefore greater monetary ease in adopting solar. For example, Canada does very poorly using this measure. This stems from the fact that the country has both low average irradiance and grid electricity prices, and higher than average system prices. It is evident from Figure 3 that some of the countries known to have high solar adoption (Germany, Spain, Italy) appear near the beginning of the graph, with lower payback periods. A correlation coefficient between this payback period estimate and cumulative solar panel adoption yields -0.36, which is the expected negative relationship but not a particularly strong one.

Generating a payback period that does incorporate discount rates is also important in order to view countries approaching grid parity and to model consumers' propensity to discount future savings. It also gives us the ability to view the strict financial viability of solar panels as an investment with current prices, electricity costs and PV efficiencies. Using Equation 3 without taking government incentives into account gives the following results:

Figure 4. Average payback period without government incentives using Equation 3 and discounting r=0.04



The examined countries without payback periods at the end of Figure 4 are countries that had not come close to reaching a value of 0 after n=100 in Equation 3. Since the future payments become increasingly discounted as n increases, these countries would probably not reach a payback period for many more years. It is also unlikely that a solar panel will have a lifespan over 100 years. The countries without payback periods have been listed in order from their proximity to zero at n=100. From this chart it is evident that Equation 2 was in fact a relatively good proxy for comparing payback periods between countries since the countries in Figure 4 are listed in about the same order as Figure 3.

In addition, this graph gives insight into where countries are in terms of grid parity. This graph indicates that Italy, Spain, Austria, Germany, the Netherlands and Portugal have all reached grid parity and would therefore be a good economic investment (on average). This estimate may also be considered to be overly optimistic since it assumes that all solar panels are installed optimally and that surplus energy generated may be sold back to the utility company at the traditional grid electricity rate. Additionally, market discount rates higher than 4% would increase payback periods.

Government incentives

Initially, dummy variables were compiled for the presence of a number of government programs offered in various countries and correlation coefficients were generated against ln of cumulative solar and ln of solar adopted in 2009 (Table 3). Recall that this is the primary method used to assess the influence of government incentives due to limitations in available information and accuracy in other more specific methods.

	ln cumulative solar	*ln 2009 solar*
FiT program	0.76	0.80
Direct capital subsidies	0.35	0.43
Green electricity scheme	0.63	0.62
PV-specific green electricity scheme	0.16	0.23
Renewable portfolio standard	0.12	0.083
Investment funds for PV	0.45	0.34
Tax credits	0.079	0.19
Net metering	-0.19	-0.017
Net billing	0.21	0.26
Commercial bank activities	0.093	0.18
Electricity utility activities	0.44	0.38
Sustainable building requirements	0.20	0.19

Table 3. Correlation coefficients for various government programs

As expected, the presence of a FiT program was the best indicator of adoption for both measurements. In fact, the correlation generated (0.76) was even higher than the correlation for system price in the preliminary monetary considerations (0.69). The FiT correlation generated against 2009 solar uptake exhibited an even stronger positive correlation (0.80). Direct capital subsidies was not as good of an indicator as expected in Hypothesis 2. This may be due to the fact that countries that have well functioning FiT systems sometimes do not offer direct subsidies. Similar reasons probably resulted in the relatively low correlations for most of the other government programs as well. For example, net metering could not be used in the presence of any FiT program; therefore, it is not surprising that it shows a negative correlation. The dummy variable that incorporated both FiTs and direct subsidies yielded a correlation coefficient of 0.72.

It is also evident from Table 3 that the two measurements of solar display similar results, but that the government incentives generally correlate to ln of 2009 solar adoption slightly better. This supports the idea that volatility of government programs make 2009 solar adoption a better proxy than cumulative adoption.

New payback periods were also developed using approximate average FiT values and direct subsidies. These results should not be weighted too heavily due to limitations in the data discussed in the Methods section, but are useful for examining the extent that government incentives may be affecting payback periods. Adjusted payback periods were generated using both Equation 2 and Equation 3.

Figure 5. Average payback period with government incentives using modified Equation 2

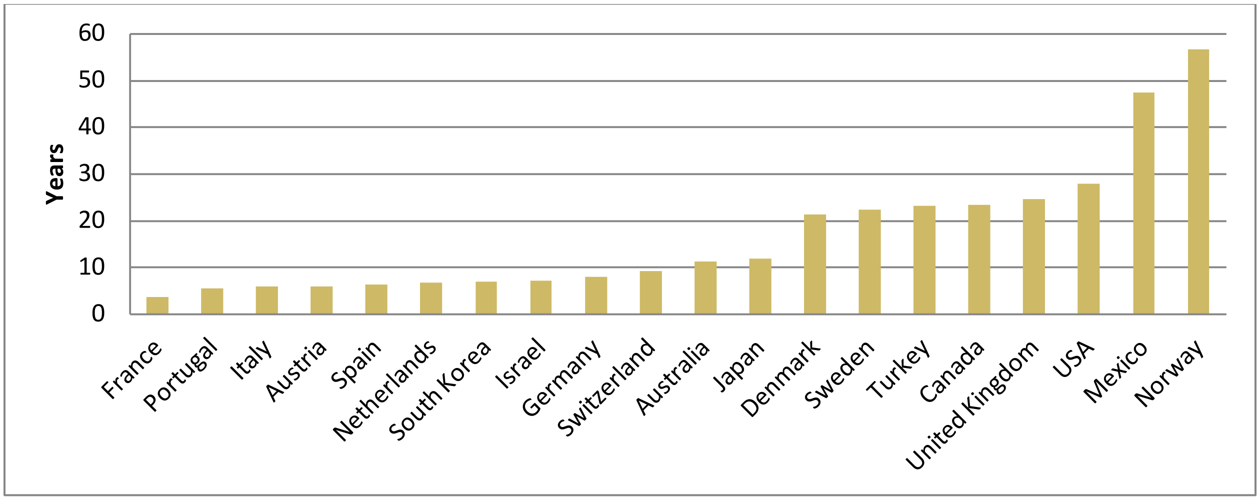
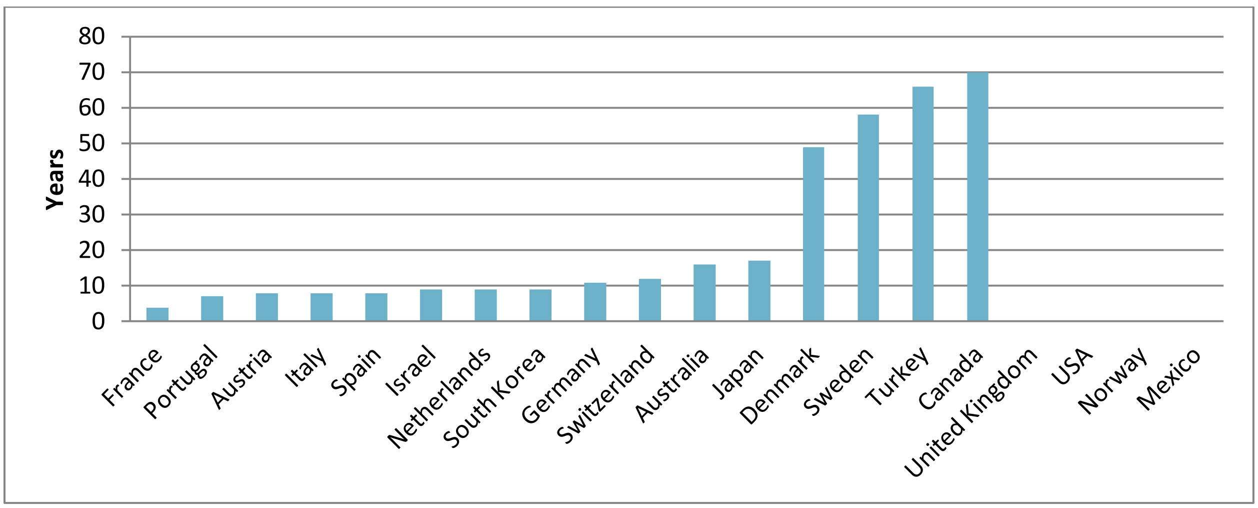


Figure 6. Average payback period with government incentives and discounting r = 0.04 using modified Equation 3



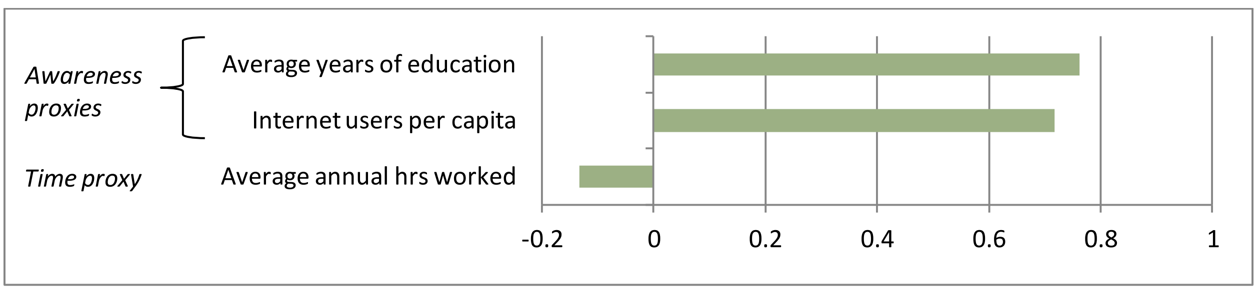
The above results indicate that government incentives have a large influence on payback period, creating conditions that make solar installation an attractive investment. Both Figure 5 and Figure 6 display many countries with average payback periods less than 40 years. Recall that this does not equate grid parity, since grid parity is only reached when solar is as good of an economic investment as grid electricity without government incentives. Overall, it seems likely from the above results that non-monetary considerations may be at play since solar is not being adopted on a large scale despite attractive monetary conditions in many countries. However, these results are only approximations.

In the final component of government incentives assessment, total PV incentives expenditure was examined[9]. 2009 public budget for PV per capita, including R&D, produced a correlation coefficient of 0.42 with 2009 solar adoption. Total demand-side incentive schemes, which excluded R&D but included all FiT schemes, produced a coefficient of 0.49 with 2009 solar adoption. In conjunction with the dummy variables and new payback periods results, this indicates the government incentives do have a substantial relationship with solar adoption.

Non-monetary considerations

This section examines a selection of the tested variables that showed the most promise as proxies for the non-monetary theories listed in Hypothesis 2. A full listing of the results for correlation coefficients generated in the preliminary round is available in Figure 11, Appendix D.

Figure 7. Correlation coefficients for bounded rationality variables with ln cumulative solar capacity per capita

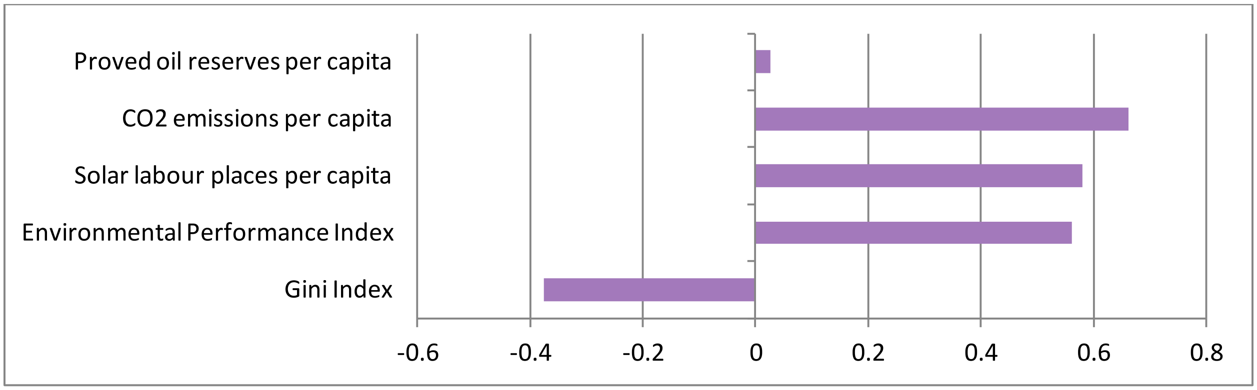


The proxies used for awareness exhibited strong correlations, indicating a strong relationship. Both average years of education and internet users per capita showed high positive correlations (0.76 and 0.72 respectively). These variables are probably also influenced by a relationship with GDP, but since both proxies showed a closer relationship to solar adoption than GDP per capita (0.63) it appears that awareness limitations do affect solar uptake. Annual average hours worked, the proxy for time limitations of bounded rationality, displayed the

[9] Recall that this variable was also not considered too heavily due limited data (total of 10 countries).

expected direction of the relationship, but was not a strong enough correlation to indicate this was a significant factor (-0.13).

Figure 8. Correlation coefficients for cognitive dissonance variables with ln cumulative solar capacity per capita



The variables for cognitive dissonance gave differing results, indicating that some or all of them were not good proxies. Oil reserves exhibited almost no correlation with solar adoption, and even went the opposite direction of expectations, exhibiting a positive correlation where a negative one was expected. However, the positive relationship is essentially meaningless considering the small value of the correlation (0.03). If oil reserves had a strong negative relationship it might be extrapolated that people with abundant oil convince themselves that environmental concerns are not serious and renewable energies such as solar are not necessary in order to reduce their dissonance (discomfort) from using their domestic resource. Therefore, even when solar becomes a good investment, consumers would selectively choose knowledge and information that would support their anti-environment view.

Perhaps cognitive dissonance was not borne out by the oil reserves results due to lack of consideration for other environmentally damaging resources[10]. CO_2 emissions per capita may be a better proxy of cognitive dissonance than oil reserves since it encompasses more polluting

[10] Consider that a country may have very low oil reserves but high coal resources, which would also result in cognitive dissonance.

practices than just oil. Note that CO_2 emissions per capita is a reflection of both consumer activity (such as home heating) and producer activity (such as energy intensive industry). It might be expected that a country that employs many of its citizens through environmentally damaging professions would experience cognitive dissonance with environmental concerns. Canada could be a relevant example of this, due to high employment and revenues from the oil sands of Alberta.

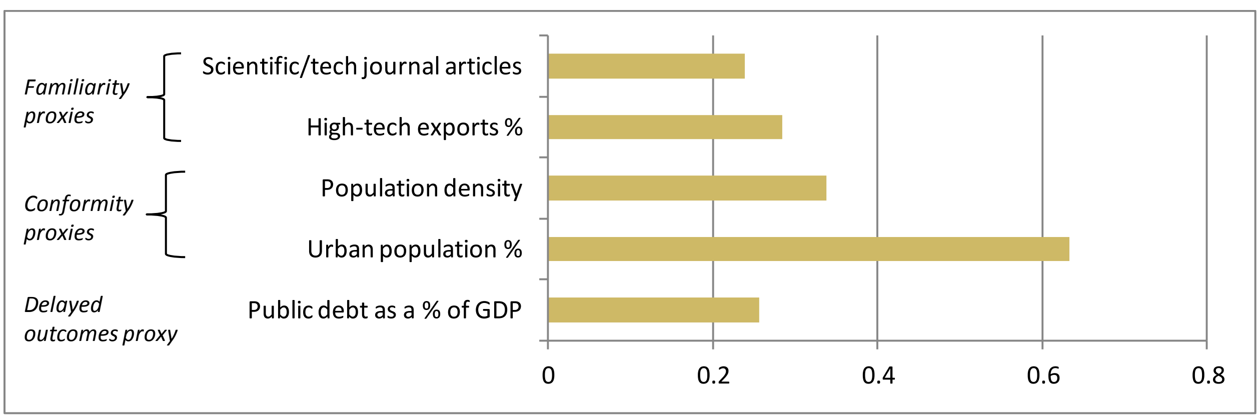
The positive relationship of the correlation coefficient generated for CO_2 emissions per capita does not support this theory (0.66). This is probably due to differences in GDP as well. To get a better understanding of the relationship between emissions and GDP, the researcher subsequently tested CO_2 emissions per capita divided by GDP per capita. This measure essentially shows the intensity of emissions – how many emissions are generated for every dollar earned. This variable resulted in a correlation coefficient of -0.47, which would support cognitive dissonance.

Another proxy used for cognitive dissonance was solar labour places per capita. This variable did exhibit the relationship we would expect in the presence of cognitive dissonance (0.58). However, this result is probably confounded by several other factors. For example, more solar labour places probably translates to more awareness. It probably also means lower domestic system prices, an important economic component.

The two indices used for cognitive dissonance were the Environmental Performance Index (EPI) compiled by Yale University and the Gini index, a well-known measure of national income inequality. EPI is scored on a range of 0-100, with 100 indicating the best environmental performance as a nation. The Gini index also has a range of 0-100, where 0 indicates perfect income equality (all incomes are equal). The EPI was used to judge environmental social identity and the Gini to judge identity on social issues in general. Both of the variables exhibited the expected relationship, which would indicate that cognitive dissonance is a factor in solar adoption.

The relationship for EPI supports the idea that a country that considers itself to be environmentally friendly in general would have higher solar adoption. Therefore we would expect EPI to have a positive relationship with solar adoption, which it does. Similarly, we might expect countries (and their citizens) that identify themselves as champions of social issues to feel compelled to take on environmental problems due to their implications for society and future generations, resulting in higher adoption of solar panels. The negative relationship with Gini index (-0.38) indicates that greater inequality within a country would mean less solar adoption. In other words, a more equal society is likely to adopt more solar which also supports the hypothesis.

Figure 9. Correlation coefficients for heuristics variables with ln cumulative solar capacity per capita



The relationships exhibited for the familiarity proxies presented in Figure 9 were not particularly strong. However, both annual number of technical and scientific journal articles published and high technology exports as a percentage of total manufactured exports displayed a positive relationship with solar adoption (0.24 and 0.28), which fits expectations since those who are more familiar with solar technology, or technology in general, are theoretically more likely to adopt[11]. However, the weak nature of the relationships suggest that these non-monetary considerations are not as important to solar adoption as some of the strong relationships found in monetary considerations.

The urban population as a percentage of total population and population density indicators exhibited positive correlations, which may be an indication that conformity and social proof are important considerations in solar adoption. Solar panels would be much more visible in dense populations, facilitating diffusion of innovations through pressures to conform to new social norms. However, this phenomenon is very time dependent, which falls predominantly outside the scope of this thesis (see Appendix C for more background on diffusion of innovations).

To examine the delayed outcomes heuristic, public debt as a percentage of GDP was used as a proxy variable. The reasoning for this was that cultures with less debt are likely to have lower internal discount rates and therefore higher solar adoption. The correlation coefficient generated did not support this theory.

However, public debt is an especially indirect proxy variable, and is probably not particularly accurate for measuring delayed outcomes. To supplement the delayed outcomes results, it is useful to return to the monetary considerations. Recall that solar system price is a much better indicator for solar adoption than future returns or even the generated payback periods (see Figure 2). This implies that consumers do not look forward into the future heavily – even if the system is a very good economic investment over time, consumers are deterred by high initial costs. This is a good indication that delayed outcomes may be present.

[11] Note that this support of the familiarity heuristic has similar implications for the awareness portion of bounded rationality.

Finally, the researcher examined the idea of status quo bias, where people tend to go with the default. For this examination, we return to the correlation coefficients generated for government programs (Table 2). The closest programs to "default" solar at the national level are probably PV-specific green electricity schemes, renewable portfolio standards (RPS) and sustainable building requirements which generated coefficients of 0.23, 0.08 and 0.19 respectively. Recall that RPS and sustainable building requirements have mandated amounts of renewable energy generation, but not solar specifically unless specified. Therefore, it makes sense that these display less relationship to ln of 2009 solar adoption per capita than PV-specific green electricity schemes. However, even this variable had a relatively weak correlation, which would indicate that status quo bias is not a large influence here, or that these are not particularly effective proxies.

V. Limitations

The researcher has made a number of assumptions while conducting this research that limit the above analysis. Efforts were made to control the number of assumptions, but some were unavoidable or limited by time.

First of all, the researcher assumed that panel efficiencies were all the same. This is probably not overly problematic since small modification innovations in technology tend to diffuse over national borders quite easily, so efficiencies are probably sufficiently similar internationally (Rogers 2003, Moore 2006). Another assumption made was that operation and maintenance costs of the PV system would be negligible. The validity of this assumption is debatable although future costs are generally considered to be very low. However, this variable may differ significantly by country due to higher costs associated with removing snow from panels in the winter.

The researcher also worked with a number of national averages. This may pose problems since some large countries have high levels of variability in these factors that may have confounded the results. For example, the average irradiance number used for the USA was 1525 $kWh/kW_p yr$. Irradiance levels are likely to be much higher in certain areas of the country (think: California), and they may therefore have rapid adoption due to more attractive monetary conditions. Since solar adoption is still in its preliminary stages, rapid adoption in one state or province of a country could make the entire country look like a leader.

In certain cases, the researcher compiled a dataset for a variable from more than one source. When this was the case, it was assumed that both sources used similar methods to obtain their data. This methodology was used for solar cumulative capacity, grid electricity price and one country for irradiance (Turkey). Due to the importance of accuracy in the solar adoption variable, almost all values were verified with more than one reputable source.

The government incentives portion of monetary considerations required the most assumptions. For the primary method used to judge government incentives and programs, the dummy variable, a value of 1 was assigned regardless of whether it was present at the federal or provincial level. This assumption probably has the most serious implications for this report. Since, for example, a federal FiT would have much more impact on national solar adoption than a single provincial one, government incentives likely have a much stronger relationship with adoption than the generated correlation coefficients indicate.

To compensate for this in part, quantification of average FiT and subsidy values and total expenditure on PV incentives was attempted. However, the researcher found that this tended to add even more assumptions and as a result, recommends that these values are not considered too heavily. In particular, many municipal programs have been overlooked since it would be impossible to procure information on all of these programs for the 35 countries evaluated. Government programs also have variability according to the type and size of the solar panel installed. For example, a direct subsidy may be available only for residential panels or alternatively only for large-scale solar farms. By lumping both the incentives and levels of solar adoption together, the researcher lost some accuracy.

VI. Conclusions

A wide range of data and variables have been examined in this thesis. The following conclusions represent the outcomes that the researcher found most interesting and most pertinent to the research questions. However, many more conclusions could be drawn by examining the results and further analysis is encouraged.

Hypotheses revisited

System price exhibited the closest relationship with solar adoption of the preliminary monetary components. A correlation coefficient of -0.69 indicates a relatively strong relationship, which defies H1 about system price, although the direction of the expected relationship holds. Average income had a relatively strong relationship with solar adoption, which is also more than expected. The hypothesized relationship did hold for grid electricity price, where a weak positive correlation was found. Solar irradiance actually had a negative relationship, while a weak positive one was anticipated. This was due to the confounding factor of where high- and low-income countries are located longitudinally. Payback periods had moderate correlations, which was hypothesized, and government incentives had differing correlations depending on the type. In particular, the presence of a feed-in tariff had an especially strong positive correlation, which fits well with the hypothesis, while direct capital subsidies had a weaker than expected positive correlation.

Overall the monetary considerations imply that the answer to the first research question is no, since solar adoption is not driven by a *full* appraisal of monetary feasibility, although the markets are certainly influenced by a number of these of these monetary factors. Specifically, the strongest correlations that came out of the economic considerations were system price, average income and presence of a FiT program.

In the correlations generated for the second question, we found indications that bounded rationality awareness limitations, conformity and the familiarity heuristic were the non-economic factors most likely to be influencing solar adoption. However, while the results for the second research question are certainly interesting, in the end they were largely inconclusive. Although some reasonable analysis of the data may be conducted, it appears that there are too many lurking variables (particularly differences in average income) to make clear judgements between two-variable correlation coefficients. An econometric model with a time series element might help isolate the influence of each variable, but would need to be very careful about dealing with multicollinearity.

Overall findings

The following table lists the ten variables, monetary and non-monetary, that exhibited the closest relationship to ln of cumulative solar capacity as evidenced through the generated correlation coefficients.

Variable	*Coefficient with ln of cumulative solar*
Presence of FiT	0.78
Average number of years in school	0.76
Internet users per capita	0.71
System price	-0.69
CO_2 emissions per capita	0.66
Average income	0.63
Solar employees per capita	0.63
Green electricity scheme	0.63
Urban population percentage	0.63
Equation 2 payback period	-0.58

Table 4. Top ten highest correlations generated

Table 4 indicates that solar adoption appears to be determined through variables that are primarily monetary or indirectly monetary in nature. For example, CO_2 emissions per capita was not a monetary consideration, but was heavily influenced by the lurking monetary variable of average income. Also interesting are the especially high correlations with the awareness proxies of bounded rationality: years in school and internet users per capita. It seems that levels of awareness might be even better indicators of solar adoption than monetary considerations.

Another noteworthy conclusion is the idea that while people appear to look at several monetary considerations, they do not necessarily appropriately weight them or conduct an analysis of monetary feasibility. This is evidenced by the lower correlations of solar adoption with payback period when compared to more visible monetary considerations such as system price and presence of incentives. It seems that consumers use simple economic indicators to make their decisions, and that variables that must be calculated to see the overall worthiness of the investment such as payback period are not utilized as much. This may explain some of the low overall levels of solar adoption, since there are high initial costs associated with solar and less visible and more complex long term benefits.

Interpretation of the strong correlations of system price and average income as compared to the other monetary variables (excluding FiT presence) would also lead to two primary conclusions. First of all, it is likely that many people do not have available funds for the upfront costs, which prevents them from solar adoption altogether. Secondly, it may indicate that non-monetary factors are at play with those that do have the funds. Bounded rationality may be a factor considering that determining future savings requires more awareness, cognitive abilities and time to ascertain than initial costs. Additionally, delayed outcomes is applicable since people appear to weight the initial costs more heavily than later savings. These findings have considerable policy implications that are discussed in the next section of this thesis.

The conclusions above are backed up when values for average payback periods are examined, which provided insight for net savings. If adoption was driven solely through monetary considerations, it would be expected that countries with payback periods less than 40 years would have much larger scale adoption than is currently present (excluding perhaps Germany). It is important to remember that government incentives have not been taken into account here, so in reality payback periods are even lower than these estimates predict. When government incentives were built into the model, solar panel installation appears to be a very attractive investment, with 12 of the 20 examined countries showing payback periods considerably less than 40 years with a 4% discount rate.

Finally, it is important to discuss the highest correlation that was generated, the presence of the feed-in tariff program. This generated a coefficient of 0.78 against cumulative solar adoption, and an even higher value of 0.80 against adoption in 2009. This is probably due to the popularity of FiT programs in countries with high solar adoption (mainly EU countries). At the offset, it might be concluded that FiTs stimulate solar adoption particularly well. However, in this case it must also be considered that FiT programs might be put in place where solar adoption is particularly popular due to political motivations, or that FiT programs are used in countries that are particularly well equipped to adopt solar. Overall, it proved to be difficult to judge the influence of government incentives since the direction of the relationship between incentives and solar adoption is unclear.

Recommendations for policy

When considering recommendations, it appears that FiT programs have had considerable success with jumpstarting national solar panel markets. However, there also appears to be potential with direct subsidies that isn't being fully utilized. This is evidenced by the higher correlation between adoption and system price than electricity price values. This also fits into the behavioural economics theories surrounding delayed outcomes and bounded rationality.

Additionally, direct subsidies could be very useful to help those who are simply not able to afford initial solar panel costs with current levels of government aid.

On the other hand, Germany appears to be having considerable success with FiTs and seems to be nearing grid parity despite relatively low solar irradiance. A similar situation is apparent for a number of other EU countries, as well as countries with larger solar manufacturing markets such as Japan. However, FiT programs may simply be a "fad" – from the results of this report it seems that direct subsidies would be a more efficient solution.

Another useful approach for governments to stimulate growth may be non-monetary approaches. While the non-monetary considerations were largely inconclusive, theoretically governments may be able to harness the power of heuristics and other cognitive decision making processes. For example, status quo bias may be taken advantage of through a "default" solar panel installation on newly built buildings that may be opted out of through paperwork. In a more extreme situation, solar panels may be required but directly subsidized in order to minimize financial burdens on consumers.

Finally, although not a stunning revelation, education, technical familiarity and environmental awareness appear to influence solar adoption. Programs to foster these may help stimulate solar adoption while having other obvious benefits to the economy and society.

Areas of further research

Considering the exploratory nature of this thesis, there are many areas of further research that could provide important information on international solar adoption. Choosing a more limited scope would help limit assumptions and maximize accuracy. It is also always important to remember that correlation does not equate causation. Controlled experiments or those on a very small scale would help solidify causation.

It might be very useful to limit a study to solely residential solar adoption, and even for a specific size panel, so that pure consumer decisions can be examined rather than including the collective decisions of businesses and utility companies. This way, government incentives may also be quantified accurately. However, complete data on residential solar adoption must be available, which it currently is not.

A researcher who is proficient in econometrics, and specifically time series multiple linear regression, could conduct a very interesting study using statistical software such as Stata. If an econometric model predicting solar adoption based on the explanatory variables in this report as well as a time series element could be generated, it could have many useful applications. It would also be very helpful for isolating the influence of specific variables.

Another interesting avenue of research could be a study focused on status quo bias that quantifies time requirements to fill out paperwork for installing solar panels and receiving government incentives. Due to a lack of appropriate proxies for status quo bias the researcher was not able to study its impact on adoption, but suspects it may be an important variable that could have implications for government policy.

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Note that sources of data are listed below in Appendix A.

Appendix A: raw data sources

Variable	*Source*	*Year*	*Sample size*
Solar cumulative capacity as of 2010	EPIA	2010	23
Solar cumulative capacity as of 2009	EPIA, IEA PVPS, REN-21 & BP	2009	35
Solar capacity installed in 2009	IEA PVPS	2009	35
Population	World Bank, CIA	2009	35
Solar system price	IEA PVPS	2009	21
Traditional grid household electricity prices	EIA, IEA PVPS	2009	28
Solar irradiance range	SEIA	N/A	30
Gross Domestic Product	World Bank	2009	35
Total electricity consumption	CIA	2007	35
Government programs	EPIA, IEA PVPS, National Reports	2009	21
Electricity production from oil, gas and coal	World Bank	2005	34
Education expenditure as percentage of GDP	CIA	2009	35
School life expectancy in years	CIA	2009	35
Proved oil reserves in billion bbl	CIA	2010	35
Gini index	CIA	2009	35
Population density in people per sq. km	World Bank	2009	34
Public debt as a percentage of GDP	CIA	2009	35
Forest area as a percentage of land area	World Bank	2010	34
CO2 emissions in metric tons per capita	World Bank	2007	34
CO2 emissions in kt	World Bank	2007	34
Annual average labour hours	OECD	2010	25
EPI	Yale University	2010	34
High tech exports	World Bank	2009	34
Solar employees	IEA PVPS	2009	18
Annual scientific and technical articles	World Bank	2007	34
Urban population percentage	World Bank	2009	34
PV budgets and expenditures	IEA PVPS, National Reports	2009	10
Life expectancy	World Bank	2009	34
Population growth as an annual percentage	World Bank	2009	34
Internet users	World Bank	2009	34

Appendix B: 2009 solar panel government programs by country

Country	*Noteworthy government activity*

Australia	- SHCP grant programme = up to 8,000 AUD for 1 kW of PV installed on residential buildings and up to 50% of cost of PV systems up to 2 kW on community buildings
	  - Household income < 100,000 AUD per year for eligibility
	  - 5,000 AUD available for system upgrades if hadn't already received grant
	- June 2009 = shift from grant based support to Solar Credits REC (Renewable Energy Certificates) multiplier
	  - 30 to 40 AUD per REC (1 REC = 1 MWh of renewable energy generation)
	  - REC multipliers = Solar Credits = for first 1.5 kW of capacity
	- State-based FiTs
	  - Ex. Australian Capital Territory FiT = **0.5291** US$/kWh for <30 kW for 20 years
	- Solar Cities Programme

Austria	- Green Electricity Act of 2003
	  - Revision active Sept 2009 = annual 2.1 million EUR for funding new installations
	- 2009 FiTs for >10kW (similar in previous years) = **0.4598-0.3998** EUR/kWh for 13 yrs
	- Fund for Climate and Energy = 19 million EUR total 2009 budget
	  - Rebates for <5 kW
	- Regional rebate program: Lower Austria = rebate <3,000 EUR/kW installed up to 5 kW

Belgium	- Energy policy is regional - Reverse metering <10 kW
Bulgaria	- Attractive feed-in tariff but concerns with degression mechanism
Canada	- Sept 2009 = shift from Ontario's RESOP (since 2006) to FIT Programme - 3 large-scale PV parks (9.1, 10 and 20 MW) have **0.42** CAD/kWh for 20 years - Ontario FIT/microFIT = fixed price up to **0.802** CAD/kWh for 20 years
China	- Single FIT in province of Jiangsu = **2.15** CNY/kWh for ground-mounted, **3.7** for rooftop, **4.3** for BIPV - Golden Sun Programme targets >500 MW
Czech Rep.	- 2009 FITs = **12.25** CZK/kWh for <30 kW, **12.15** CZK/kWh for >30kW for 20 years
Denmark	- Net-metering scheme but no incentives
France	- FIT and tax credit since 2006 - FIT 2009 = **0.32823** EUR/kWh with BIPV bonus of **0.27353** EUR/kWh for 20 years - Tax exempt proceeds from PV electricity sale when <3 kW - Income tax credit for 50% of system capped at 8,000 EUR/income tax paying person - ADEME-FACE support for off-grid systems
Germany	- Renewable Energy Sources Act (EEG) - FIT 2009 = **0.3194** EUR/kWh for ground mounted, **0.4301** EUR/kWh rooftop PV <30 kW, **0.4091** EUR/kWh rooftop PV <100 kW, **0.3958** EUR/kWh rooftop <1 MW, **0.33** EUR/kWh rooftop >1 MW - Pre-defined corridor for FIT adjustment - Reimbursement for own consumption when <30 kW - Also, local tax credits and state-owned bank KfW-Bankengruppe provides loans
Greece	- Attractive FIT since 2006, but high administrative burden
India	- National Solar Energy Mission attempting a FIT
Israel	- FIT introduced in 2008 at 2.04 NIS/kWh - FIT 2009 = **1.97** NIS/kWh for <50 kW - Focus on households and small commercial applications
Italy	- 2009 = Primo Conto Energia = PV plant installations - FIT (started in 2007) for 2009 = **0.4802-0.3528** EUR/kWh, reduced 2% per yr for 20 yrs

	- Additional amounts earned from sale to grid or own consumption - Some grant support for BIPV

Japan	- Subsidy program = Act on the Promotion of the Use of Non-Fossil Energy Sources and Effective Use of Fossil Energy Source Materials by Energy Suppliers
	  - July 2009 = obliges electricity utilities to purchase surplus PV power
	  - Nov 2009 electricity prices from PV = **48** JPY/kWh for <10 kW, **39** JPY/kWh combination, **24** JPY/kWh for <500 kW
	- Focus on residential systems
	- 2009 budget for PV power generation = 49,560 million JPY

Malaysia	- National MBIPV Project = various incentive programmes with caps - Proposed feed-in tariff for 2011
Mexico	- Private sector drives grid-connected projects
The Netherlands	- Stimulation Sustainable Energy Production (SDE) = FIT scheme - 2009 FIT = **0.526** EUR/kWh for 0.6-15 kW, **0.459** EUR/kWh for <100 kW for 15 yrs - Higher FITs for 2008 - Additional city-wide initiatives
Norway	- Mainly off-grid applications - No PV demonstration, field test or market stimulation programmes in 2009
Portugal	- IPP law = FITs of **0.317-0.469** EUR/kWh for power producers, **0.291** EUR/kWh for <150 kW, **0.65** for <5.75 kW - Income tax reductions on solar equipment up to 800 EUR - Four large projects in 2009: 1.44 MW, 5 MW, 6 MW, 10.1 MW
Slovenia	- June 2009 = FIT for 15 years with 7% degression rate
South Korea	- 2009 budget for PV = 401,469 million KRW - Subsidy of 60% of initial PV system (<50 kW) cost for private houses and 100% of cost for public multi-family rental houses - Late 2008 reduction in feed-in tariff
Spain	- Sept 2008 = Royal Decree 1578/2008 dramatically reducing solar support scheme - Late 2009 FiTs = **0.34** EUR/kWh, **0.32** EUR/kWh, **0.28** EUR/kWh with degression rate
Sweden	- No subsidy scheme from Jan-July 2009 - July 2009 = 60% of project costs to max of 2 million SEK - Regional initiatives such as Solar Region Skane - Single local feed-in tariff
Switzerland	- FIT 2009 = similar to Germany with payments for 25 years - Federal subsidy = 2900 CHF/kW installed (similar amount in Canton subsidies) - Excludes from FiTs for first 3 years - Swiss solar stock exchange schemes
Taiwan	- Mostly grid-connected rooftop installations
Thailand	- 2009 FIT = additional **11** THB/kWh for 10 years - Also tax incentives, free technical assistance, investment grants, soft loans, government co-investment scheme
Turkey	- Mainly off-grid, but plans for a FIT
UK	- 2009 Low Carbon Buildings Programme = grants for households of lower amount from 2,000 GBP/kW maximum or 50% of relevant eligible costs - Introduction of a FIT in 2010
USA	- 30% federal investment tax credit - 2009 state-wide performance based incentives: 11 FITs, 14 production incentives (non-FITs), 14 REC purchase programs - RPS in 29 states, with solar specifications in 16 - PACE programs in 18 states and 30 municipalities, offering loans for PV systems

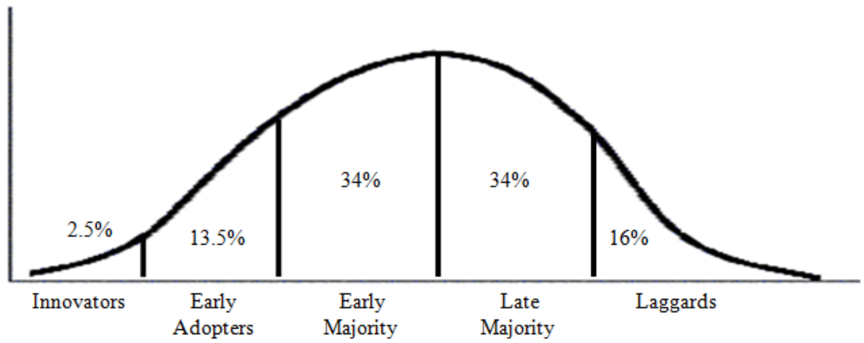
Appendix C: extended discussion on behavioural economics

The main element of behavioural macroeconomics that applies to this thesis is the concept that individuals do not make their purchasing decisions in isolation. This is a process which is heavily dependent on a time element, which is beyond the scope of this research. Quantifying the time element in econometric terms is also beyond the expertise of the researcher, but a qualitative analysis of its potential influence on solar adoption would be worthwhile for the reader to gain a better understanding of the various solar markets. In particular, it may give insights about how a market like Germany's might take off and become a self-propelled force through social factors.

Since presumably the readers of this thesis were once teenagers, we all know that social pressures can be very influential in decision making. Behavioural macroeconomists are increasingly trying to include social factors in their models of decision making, which has resulted in an explanation of why some worthwhile products become totally ingrained in society while other equally worthy products do not. Solar panel technology would benefit greatly from understanding and implementing the strategies that would bring about increased adoption.

In 1962, Everett Rogers published his book *Diffusion of Innovations*. This model of aggregate decisions explains how a new technology tends to move through society and identifies five main stages of the adoption process. Each stage also represents a distinct type of consumer. For example, descriptors of innovators often include adventurous, risk-taking and curious (Rogers, 2003, p. 282). In society, innovators tend to be affluent, young and well-educated (Moore, 2006). Innovators get the ball rolling on a new technology – in the case of solar panels, they would likely be the first to install them on their homes.

Figure 10. Adopter categorization on the basis of innovativeness, modified from Rogers 2003, p. 281



However, innovators are not necessarily the most influential members of society, and the majority of the population does not follow directly from these eager individuals. Rogers explains how an innovation diffuses through a population in the following way (2003). After the innovators come early adopters, who often include the most respected members of society – people with high status and leadership ability. The decision of the early adopters dictates the further diffusion of the technology into society. The early majority and late majority tend to follow based predominately on social factors; they look to their society's early adopters for the go ahead. This explains why tie-dye, bellbottoms and shoulder pads all somehow went into (and subsequently out of) fashion. The last step to total diffusion is when the laggards adopt the product. These people tend to be the traditional, older segment of the population.

Roger's adopter category	*Roger's description*
Innovators	Venturesome, cosmopolitan, high financial resources, high technical knowledge, ability to cope with high uncertainty
Early adopters	Respected, integrated part of the local social system, opinion leaders
Early majority	Deliberate, high interaction with peers
Late majority	Sceptical, often motivated by social factors, dislike uncertainty, may have limited resources
Laggards	Traditional, localite, suspicious of innovation and change, may have limited resources

Table 5. Characteristics of Roger's adopter categories, modified from text in Rogers 2003, p. 282-285

Many economists have subsequently made alterations to Rogers's ideas on the diffusion of innovations. Moore's model may be particularly relevant to solar panel adoption, since he focuses on high technology products, which often fail to diffuse naturally to the majority of society due to complexity. Moore identifies a crucial gap in the diffusion process between the early adopters and early majority. He claims that this phase is where many high tech products fail to gain momentum and become fully diffused in society, and calls this critical time period the "chasm" (Moore 2006, p. 5).

In the context of solar panel adoption, the chasm is where advocates should be worried. Studying where solar panel adoption currently lies in the diffusion of innovations framework would help identify whether individual national markets are approaching, falling into or crossing the chasm. Studying correlated indicators for which factors influence solar adoption (like this thesis does) should tell us what is allowing them to do so, or conversely, facilitating their failure.

Appendix D: additional tables and figures

Figure 11. All tested non-economic indicators

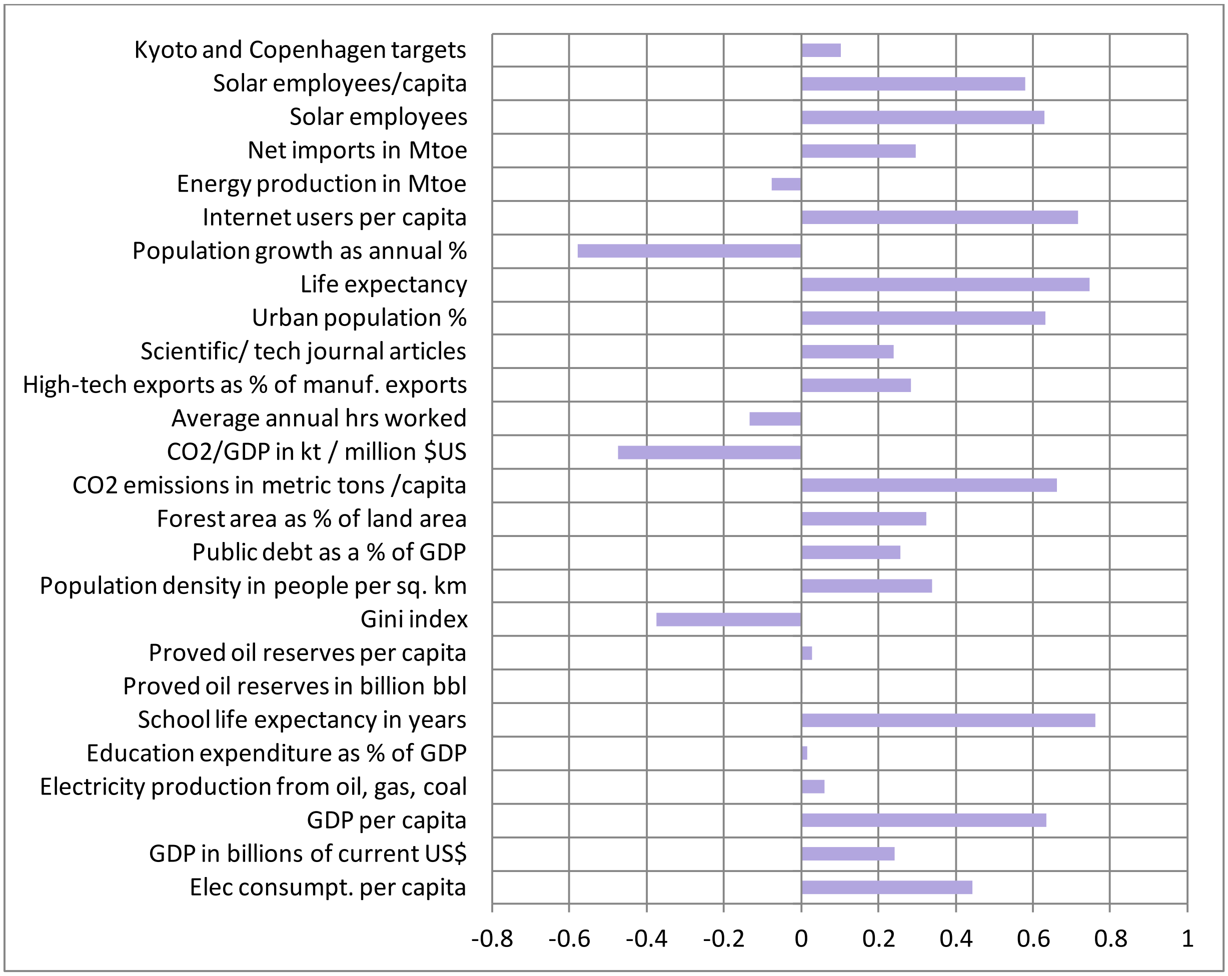


Figure 12. Payback period including direct subsidies with discount factor r=0.04

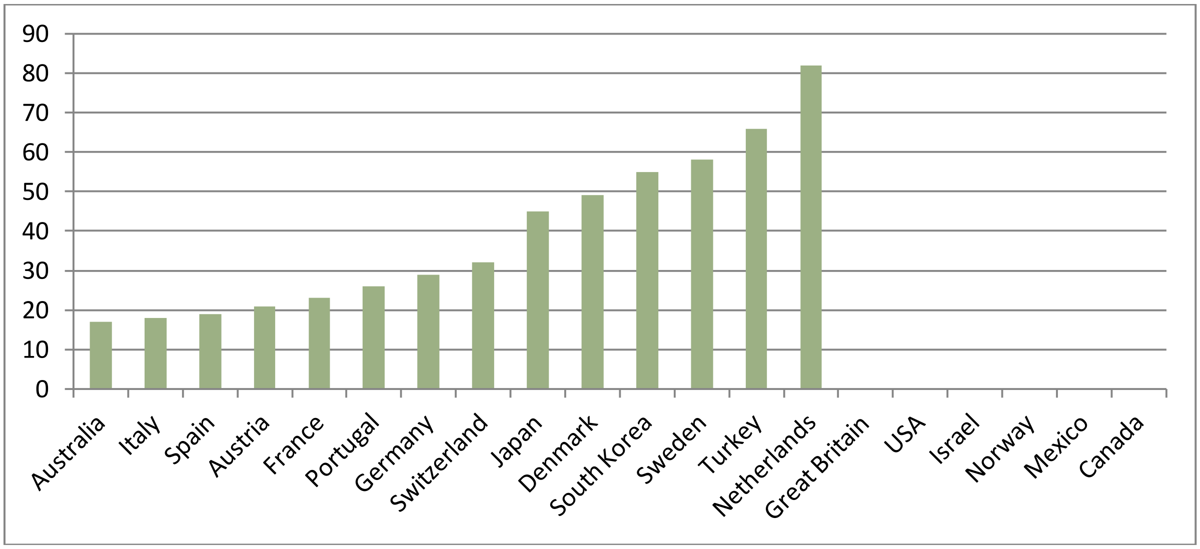
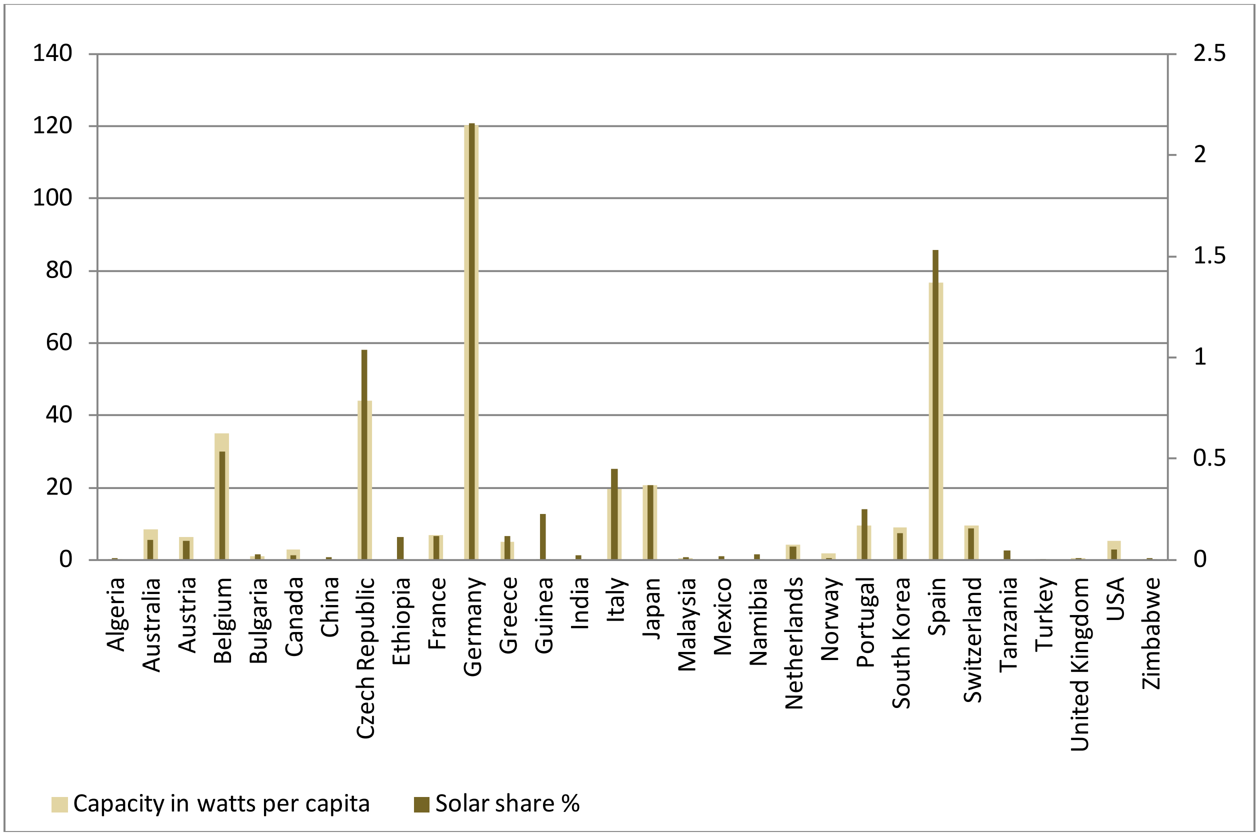


Figure 13. Measuring solar adoption by capacity per capita vs solar share of electricity using 30 selected countries



Country	*Equation 1 payback period*	*Equation 2 payback period*	*Equation 1 pp with govt incentives*
Australia	24	79	12
Austria	16	25	7
Canada	93	>100	24
Denmark	22	49	22
France	30	>100	4
Germany	17	29	9
Israel	30	>100	8
Italy	13	18	7
Japan	21	45	12
Mexico	48	>100	48
Netherlands	19	33	7
Norway	57	>100	57
Portugal	19	35	6
South Korea	45	>100	7
Spain	13	19	7
Sweden	45	>100	23
Switzerland	28	>100	10
Turkey	24	66	24
United Kingdom	39	>100	25
USA	41	>100	29

Table 6. Payback periods by country with various equations

Figure 14. 2009 cumulative installed solar capacity by country in MW excluding 10 leaders