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Environmental, Generation and Policy Determinants of Feed-in Tariff: a Binary Pooling and Panel Analysis

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Abstract

In this paper we analyze the key-factors behind the adoption of the Feed-in Tariff. We propose and test two regression models for binary data: a pooling specification and a panel one. We employ a comprehensive sample of 60 countries with distinct economic structures over the period 1980–2008. Economics, environmental and generation factors are used as regressors and results demonstrate that these factors are relevant for the policy decision to adopt the Feed-in Tariff. Furthermore, the panel specification appears a better specification, in a such heterogeneous context, than the classical pooled specification.

1 Introduction

Nowadays, about 80% of electric power is generated by fossil sources (coal, gas and oil), but there are growing global concerns regarding the lack of sustainability of these forms of electricity generation that bring into question their use in long–term energy development strategies. During the last decade in order to respond to energy–related challenges such as climate change, air pollution, volatility in fossil fuel prices, and a growing demand for electricity, countries have multiplied recourse to renewable energy sources (RES). RES are becoming increasingly important in the energy generation mix of countries, because they can reduce global climate change, the dependence on imported fossil fuels, but they also promote the local economic development. For this reasons, governments have adopted a wide variety of grants and /or incentives aimed to support renewable energy investments.

There is a wide range of policies being used to support renewable energy development around the world, including Feed–in Tariff (FiT), renewable portfolio standards (RPS), economic tools, distributed generation measures and disclosure and green marketing measures. FiT and RPS are two of the most popular policy instruments. A FiT program typically guarantees that customers who own a FiT-eligible renewable electricity generation facility, such as a roof-top solar photo-voltaic system, will receive a set price from their utility for all of the electricity they generate and provide to the grid.

A brief overview of the main policy instruments being used to promote RES can be found

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in a recent report by the *United Nations Environment Programme* (UNEP, 2012). The report produced by the UNEP highlights that FiT is the most applied national policy instrument to promote RES.

There is plenty of literature about RES and policy instruments and, for sake of simplicity, it can be divided in two main topics: the former, in which authors describe and assess FiT policies and the latter in which policies are included in the key factors of investments in RES. Lesser and Su (2008) propose an innovative two–part FiT, consisting of both a capacity payment and a market-based energy payment, which can be used to meet the renewable policy goals of regulators. They find that the proposed two–part tariff design draws on the strengths of traditional FiT, relies on market mechanisms, is easy to implement, and avoids the problems caused by distorting wholesale energy markets through above-market energy payments. Del Rio (2012) builds a theoretical framework for dynamic efficiency analysis and assess the dynamic efficiency properties of the different design elements of FiTs. He shows that several design elements can have a significant impact on the different dimensions of dynamic efficiency. Particularly relevant design elements in this context are technology-specific fixed–tariffs, poor prices, reductions of support over time for existing plants, long duration of support and support falling on consumers. Dong (2012) analyzes the effectiveness of FiT and renewable portfolio standard (RPS) in the development of wind generation. He finds that FiT policies have a positive effect on RES development while RPS policies have a negative effect. Other authors (Islam and Meade, 2013) using data from Ontario, where a generous FiT is available to households generating electricity from solar panels, measure household level preferences for panels and use these preferences along with household characteristics to predict adoption time intentions. Hsu (2012) employs a system dynamics model in order to develop a simulation for assessing which policy, or combination of policies, promoting solar PV applications has the greatest economic benefit. The simulation period is from 2011 to 2030. He finds that FiT price or subsidy is a good approach. Stokes (2012) presents a case study of Ontario's FiT policies between 1997 and 2012 to analyze how the political process affects renewable energy policy design and implementation.

Other studies examine the drivers of RES development and include the policy grants in order to quantify the effect of these instruments in the promotion of RES. Among these the most interesting (Menz and Vachon, 2006; Carley, 2009) study the renewable investments in the USA, the former with a regression into countries and the latter using a panel regression while Marques et al. (2010) analyze the drivers promoting renewable energy in European countries and find that lobbies of traditional energy source and CO_2 emission restrain renewable deployment. Evidently, the need for economic growth suggests an investment that supports, but does not replace, the before installed capacity. Romano and Scandurra (2011) analyze the investments in RES in low carbon and high carbon economies using a panel dataset. More recently the same Authors study the key factors promoting the investments in RES in a panel dataset of Petroleum Exporting Countries (OPEC) members (Romano and Scandurra, 2014 and Romano et al., in press), and the role of economic growth as driver of the FiT adoption (Romano et al., 2015). In the first case, lack of grants and/or incentives to promote the installations of new renewable power plants has been considered a limit for the sustainable development of the OPEC countries, in the second it came to light as the economic growth is one of the main driver of the FiT adoption.

The aim of the paper is to identify the determinants driving a country's choice of adopting FiT policy. We address this issue using a static panel probt model estimated over a pooling and panel specification as longitudinal analysis can improve the results. For this reason we use a comprehensive dataset of 60 countries with distinct economic and social structures as well as different levels of economic development in the years between 1980 and 2008.The sample includes OECD, South American, Asian and African countries. This dataset can be helpful to assess the effect that macroeconomic variables have in order to suggest to policymakers the need to adopt the FiT. The organization of the paper is as follows: Section 2 describes data and scope of the work while Section 3 analyzes the models proposed and reports the empirical results discussing about the policy implications. Section 4 contains a comparative analysis between the pooling and panel specification. Concluding remarks are given in Section 5.

2 Data and scope of the work

The empirical analysis is based on a large dataset of 60 countries with different economic and social structures. We use annual data from 1980 to 2008 obtained from the *U.S. Energy Information Administration* (EIA) and *International Renewable Energy Agency* (IRENA). All the countries in the sample have a share of electricity generated by RES but around 40% of our sample does not adopt the FiT. In this way we include in the sample also countries that generate electricity with RES but do not adopt this policy instruments to promote new RES power plants.

The variables used limit the major economic, generation, and environmental factors from which investment decisions are originated and influence the policymakers. As in the UNEP report (UNEP, 2012) we classify the explanatory variables in four homogeneous factors:

- Environmental (total CO_2 emission from energy consumption);
- Economics (per capita electricity consumption; GDP per capita; energy security);
- Generation (share of non–hydroelectric renewable generation; share of nuclear generation; share of fossil generation);
- Policy (adoption of Kyoto protocol).

Among environmental factors we include the total carbon dioxide emissions from the consumption of energy that capture the environmental degradation due to economic development. The International Energy Agency evaluates that CO_2 from energy represents about three quarters of the anthropogenic GHG emissions for Annex I[2] countries, and

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[2] The Annex I Parties to the 1992 UN Framework Convention on Climate Change (UNFCCC) are: Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, the Czech Republic, Denmark, Estonia, European Economic Community, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, the Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom and United States. See www.unfccc.int.

over 60% of global emissions. This percentage presents high variability by country, due to different national structures (IEA, 2013). The choice to include in the regressors the total CO_2 ($lnCO_2$) instead of the per capita CO_2 seems appropriate because international agreements binding targets for reducing total greenhouse gas (GHG) emissions. In fact, CO_2 emissions are one of the main factors of the greenhouse effect and actions have been embraced to reduce it. Obviously, the carbon dioxide emission is a proxy for environmental degradation. The expected result is a significant positive effect. The more the emissions are, the more should be the probability to adopt the FiT.

Economic factors includes GDP per capita (lnGDP), per capita consumption of energy (lnCons) and the energy security of supply (Import). The GDP is one of the most important economic indicators. It is commonly assumed that richer countries are able to better promote investments in RES, employing various forms of grants and incentives. GDP is also related to energy consumption, which is considered a proxy for economic development of the country (Toklu et al., 2010). The increasing energy consumption leads policymakers to build new power plants based on renewable sources, better technology or economic structural changes. In the literature this is associated to a higher strength in environmental degradation. A similar argument can be applied to energy security, approximated by the degree of dependence on foreign supplies of electricity. As known, the power grid interconnections allow a constant exchange of electricity between countries. The need to increase their share of generation (and to reduce electricity dependence) could increase the probability of adopting policies to support the RES development.

Among generation factors we include the share of non–hydroelectric renewable generation (ShRENNH), i.e. the ratio between non–hydro renewable generation and total net electricity generation that can be also considered a proxy of investments in RES (Romano and Scandurra, 2014; in press). The effect is expected positive. Countries are encouraged to increase the share of electricity generation from RES. We include the non–hydroelectric generation because, generally, FiT is mainly related to promote the investments in these source (mainly photo-voltaic and wind generation) rather than hydroelectricity.

Much of the world's electricity is generated thermally using non–renewable (fossil) fuels. Thermal generation (ShTHER) has both a high environmental impact and presents increasing generation costs. Despite the growth of non–fossil energy, the share of fossil fuels within the world energy supply is relatively unchanged over the past 40 years. In 2011, fossil sources accounted for 82% of the global TPES. Generation of electricity and heat worldwide relies heavily on coal, the most carbon–intensive fossil fuel. Countries such as Australia, China, India, Poland and South Africa produce over two-thirds of their electricity and heat through the combustion of coal (IEA, 2013). Finally, among generation factors we also include the share of nuclear generation (ShNUC). The nuclear energy generation occurs only in some countries, mainly rich countries and it is CO_2 free.

As policy factors we include a dummy variable that indicates the adoption of Kyoto protocol. The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits industrialized countries (as a group) to curb domestic emissions by about 5% relative to 1990 by the 2008–12 first commitment period. Alongside the agreement to negotiate a new climate agreement by 2015, 38 countries have agreed to take commitments under a second commitment period of the Kyoto Protocol to begin in 2013.

Clearly, not all aspects of a complex phenomenon like the decisions to adopt some grants for investments in renewable energy can be disclosed in the present work. Some critical issues, such as the reprogramming of the energy plan, problems related to the population, the environmental impacts of new power plants, are not taken into account but they are factors that can affect the decisions.

3 The models

3.1 The static probit model

Let us define $Y_t \in \{0, 1\}$ the binary time series at time t. The linear predictor of the static probit model (Greene, 2003) is defined as:

$$\pi_t = \alpha + x'_{t-k}\beta. \tag{3.1}$$

with t = 1,...,T

It assumes that the expected value of Y_t conditionally on information at time *t-k* is given by

$$E(Y_t) = p_t = \Phi(\pi_t)$$

where $\Phi(\cdot)$ is the cdf of a standard normal distribution.

The main feature of the static model is that it does not consider lagged dependent variables as regressors.

For this reason only exogenous lagged variables are used as regressors. Probit models are often presented in a dynamic specification (Estrella and Mishkin, 1998; Kauppi and Saikkonen, 2008; Nyberg, 2010; De Luca and Carfora, 2014). Here, the choice of the static specification is due to the specific nature of the outcome variable, not compatible with a dynamic specification, considering that a country's choice to adopt the tariff represents a medium term strategy in environmental policy. Following eq. (3.1) the static probit model is:

$$\begin{aligned}\pi_t = \alpha + \beta_1 lnCO_{2t-1} + \beta_2 lnCons_{t-1} + \beta_3 lnGDP_{t-1} + \beta_4 Imports_{t-1} + \\ + \beta_5 ShRENNH_{t-1} + \beta_6 Kyoto_t + \beta_7 ShTHER_{t-1} + \beta_8 ShNUC_{t-1}.\end{aligned} \tag{3.2}$$

We calculate maximum likelihood estimators of the parameters and listed them together with their standard errors in Table 1.

The coefficients are in line with the expected results. Among the significant coefficients, except for the electricity consumption, that (as expected) is negatively linked to the outcome variable, the increase in one of the explanatory variables is directly related to the increase in the probability to adopt the FiT. This is an important result that suggests that countries consider the FiT as an useful instrument to promote the RES to reduce the carbon emissions (especially after the subscription to the Kyoto protocol). Moreover there is a direct relationship between the FiT adoption and tendency of the GDP. The coefficient of the net imports is not significant. This is due to the presence, of countries that depend on others for their electricity consumption. This is an interesting issue in the analysis of the phenomenon and for this reason we do not drop the variable by the model-specification. Energy security is a relevant aspect in the electricity models but it does not relevant in

Table 1: Estimates, standard errors, p-values of the Static Probit Model.

Variables	Estimates	Std Errors	P-values
$Constant$	-9.274	1.295	0.000
$lnCO_{2t-1}$	0.344	0.036	0.000
$lnCons_{t-1}$	-0.196	0.114129	0.087
$lnGDP_{t-1}$	0.686	0.145	0.000
$Imports_{t-1}$	0.043	0.027	0.110
$ShRENNH_{t-1}$	3.862	1.001	0.000
$ShTHER_{t-1}$	-0.094	0.184	0.611
$ShNUC_{t-1}$	-0.168	0.320	0.600
$Kyoto_t$	1.122	0.096	0.000

the decision to adopt FiT. Furthermore, by the analysis of the coefficients we observe that a relationship between the outcome variable and thermal and nuclear generation factors, being this type of policy unconnected with these factors, does not exist. Maybe electricity demand, is mainly supplied by the traditional sources of energy which are still independent from the innovative policies. Also these issues appear interesting and lead us to let these variables in the model specification.

3.2 The panel probit model

We improve the traditional probit model attempting to explain the probability that a country will adopt the FiT in terms of exogenous variables and individual characteristics too. This approach includes determinants related to the heterogeneity in the dataset following a panel specification of the traditional static model.

The panel model is the following:

$$\pi_{i,t} = \omega + x'_{i,t-k}\beta + u_i + z_{i,t}. \tag{3.3}$$

where $z_{i,t}$ represents the error term and u_i denotes a country-specific random effect and u_i + $z_{i,t}$ = $\epsilon_{i,t}$. The assumption on u_i is that it is i.i.d drawn from a univariate normal distribution or $u_i \sim N(0; \sigma_u)$ (Vella and Verbeek, 1998).

As in the pooling specification (3.1), it occurs that:

$$E(Y_{i,t}) = p_t = \Phi(\pi_{i,t})$$

The individual specific unobserved effects are uncorrelated with the independent variables and with the error terms. For the estimation of the coefficients of the panel binomial models (logit and probit) are often used fixed effects estimator (Jakubson, 1991) or procedures based on instrumental variables (see, e.g., Hausman and Taylor, 1981; Amemiya and McCurdy, 1986). Pinheiro and Bates (1995) review several methods to calculate the parameters in a generalized linear mixed effect model maximum likeklhood (ML) procedures. In this work the maximum likelihood method proposed by Vella and Verbeek(1998) has been used in order to estimate the parameters in (3.4) (derived directly by the 3.2), and the unobserved heterogeneity σ_u of the random effects probit model. Due to the presence of time-invaring variables (like the energy imports or share of nuclear generation, constantly equal to zero for several countries), the choice of a random model appears as the most appropriate specification. In fact, using a fixed-effects model that eliminates the effects through time-demeaning, time-constant variables will be drop out too. Therefore, the use of time-demeaning variables is equivalent to introducing a full set of individual dummies, that, taken together, would be collinear with any time-invariant ones.

$$\begin{aligned}\pi_{i,t} = \omega + \beta_1 lnCO_{2i,t-1} + \beta_2 lnCons_{i,t-1} + \beta_3 lnGDP_{i,t-1} + \beta_4 Imports_{i,t-1} + \\ + \beta_5 ShRENNH_{i,t-1} + \beta_6 Kyoto_{i,t} + \beta_7 ShTHER_{i,t-1} + \beta_8 ShNUC_{i,t-1}\end{aligned} \tag{3.4}$$

In Table 2 we summarize the results obtained by the maximum likelihood estimation of the parameters under the panel specification (3.4).

Table 2: Estimates, standard errors, p-values of the estimated Panel Probit Model.

Variables	Estimates	Std Errors	P-values
$Constant$	-9.656	1.392323	0.000
$lnCO_{2t-1}$	0.349	0.03926	0.000
$lnCons_{t-1}$	-0.236	0.123001	0.055
$lnGDP_{t-1}$	0.741	0.15586	0.000
$Imports_{t-1}$	0.057	0.034049	0.095
$ShRENNH_{t-1}$	3.229	1.075743	0.003
$ShTHER_{t-1}$	-0.168	0.194903	0.388
$ShNUC_{t-1}$	-0.160	0.334758	0.633
$Kyoto_t$	0.423	0.181158	0.020
σ_u	1.114	0.28393	0.000

The coefficients of the panel model are in line, both in signs and in the intensities, with those estimated in the model under the pooling specification. Under the panel specification, also the coefficient related to net imports becomes significant event though at 10 per cent level. This is due to the use of the panel random effect (RE) model specification and hence of the correct error covariance that, eliminating the endgeneity between error terms and regressors, returned a more consisted estimator. Moreover, the significance of the standard deviation (σ_u) of the effects confirms the presence of the heterogeneity between the countries and validates the choice of the random model.

4 Comparison of model specifications

The selected variables used to describe the key-factors underlying the decision of a country to adopt the Feed-in Tariff seem to be adequate to describe the phenomenon and the results, both of the models under the pooling and under the panel specification. Moreover, results appear to be consistent with the theoretical implications recognized in literature.

The aim of this work is also to assess if, in presence of an heterogeneous set of countries observed in different years, a panel specification can be a valid tool to obtain more appropriate estimates. Moreover we try to improve the results capturing, once isolated, the variability of the country specific effects that is part of information that in a pooling specification should be turned up in the residual component. To reach this goal we have calculated, both for the pooling and for the panel model a set of most commonly used fitting measures. These are:

1. The value of $maximized\ loglikelihood$ of the model
2. The $Akaike\ Information\ Criterion$ - AIC (Akaike,1974)

$$AIC(r) = -2\ell + 2r$$

where ℓ is the maximized log-likelihood of the model and r denotes the number of parameters estimated.

3. The $pseudo - R^2$ proposed by Mc Fadden(1973)

$$R^2_M = 1 - \frac{\ell_1}{\ell_0}$$

where ℓ_1 is the maximized log-likelihood of the considered model and ℓ_0 is the maximum of the log-likelihood function under a Null model without any explanatory variable.

And, finally, as index of predictive accuracy,

4. The $Mean\ Absolute\ Error$ (MAE):

$$MAE = \left(\frac{\sum_{i=1}^{N} \sum_{t=1}^{T} |Y_{i,t} - \hat{\pi}_{i,t}|}{NT} \right), \tag{4.1}$$

where $\hat{\pi}_{i,t}$ is the fitted probabilities under the panel model to adopt the FiT. With t starting in 1981 and ending in 2008 (T) for a total of 28 years and $i = 1, ..., 60$ corresponds to the 60 countries under study.

Table 3: Measures of comparison of models.

Specification	Maximum Loglikelihood	AIC	R^2_M	MAE
Pooling	-500.77	1019.54	0.33	0.18
Panel	-487.45	994.90	0.35	0.18
LRT test	χ^2 statistic: 26.64 (0.000)			

Table 3 reports the different measures used to compare the goodness of fit, the predictive accuracy of different estimated models and results of Likelihood ratio tests (LRT) to test the pooling restriction of the static probit model. While using MAE, there is no difference between the two models, other results indicate the panel as the better specification. Moreover, results of the Likelihood Ratio Test (LRT), lead us to reject the null hypothesis of indifference between the two models in favour to the panel parameterization (χ^2 statistic: 26.64; p-value: 0.000). Thus, a panel model including also individual components is the better model to evaluate the determinants of a country's choice to adopt the FiT.

5 Conclusions

This study has two essential aims: *i)* identify the variables related to the decisions of a country to adopt an incentive as a Feed-in Tariff to promote the investments in RES and *ii)* find an appropriate model specification to extrapolate informative contents from an heterogeneous set of countries.

Regarding the former, both the models return positive and similar responses, reaching the main goal of the analysis. Almost all selected variables are significant on the decision to appeal to the incentive. In particular, the absolute value of the CO_2 emissions assumes importance both as impact on the population of the level of pollution and as emissivity measure of the efficiency of the generation process in a country. In fact, the collapse in the price of RES observed in recent years, put forward the latter as a viable alternative to expensive plant system upgrades necessary to cut CO_2 emissions. The increasing probabilities to promote the electricity generation from RES that emerge from this model, strengthen the evidence of the widespread use of energy policies oriented towards generating conversion from RES. In the same way should the results related to Kyoto variable be interpreted. Moreover, the economic growth is certainly one of the major cause of the FiT adoption. As GDP level increases and living conditions improve, countries try to introduce some policy incentives for the RES. The results related to the electricity consumption in both models are also in line with the theoretical outcomes. From our results, it emerges a plausible support of the causality between reduction in the electricity consumption and the tendency of the policy makers to introduce the tariff in order to promote energy efficiency.

As for the second aim of the analysis, panel specification appears appropriate both in terms of more significance of the estimates and of indexes of goodness of fit. Instead of the sub-optimal pooled specification, the random effects panel specification can be used as a better model especially when the phenomenon analyzed is observed in an heterogeneous contest. Furthermore, it can be a valid instrument to draw the individual specific features, especially when they are full of informative contents that, otherwise, could not completely emerge in a pooling specification. Finally, the purpose of the authors is to develop, based on empirical results obtained, methods able to estimate the probabilities of FiT adoption for countries that have not yet done it and to measure the effect of economic, environmental and generation factors on the decision to adopt FiT.

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Appendix

Estimation of model and all the data analyses were done using pglm package (Croissant, 2013) implemented in R statistical software. The package is available on the CRAN package repository (www.cran.r-project.org) while codes used to obtain reported results and all additional information useful to make research reproducible will be made available by the authors on request. Data employed are freely available from U.S. Energy Information Administration (www.eia.gov) and International Energy Agency (www.iea.org).