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How Fit are Feed-in Tariff Policies?

Evidence from the European Wind Market

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Abstract

Feed-in tariffs have become the most widely used policy instrument to promote renewable energy deployment around the world. This paper examines the relation between tariff setting and policy outcome based on wind capacity expansion in 35 European countries over the 1991–2010 period. Using a dynamic panel data model, it estimates the long-run elasticity of wind deployment with respect to the level of feed-in support. The analysis finds that higher subsidies do not necessarily yield greater levels of wind installation. Non-economic barriers and rent-seeking may have contributed to the weak correlation. On the other hand, the length of feed-in contract and guaranteed grid access are important determinants of policy effectiveness. A one-year extension of an original 5-year agreement on average increases wind investment by 6 percent annually, while providing an interconnection guarantee almost doubles wind investment in one year.

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How Fit are Feed-in Tariff Policies? Evidence from the European Wind Market

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1 Introduction

Governments have implemented various incentive programs to accelerate renewable energy deployment around the world. In the 1970s and 1980s, the policy emphasis was to support technology research and development. In the 1990s, the focus gradually shifted to stimulate market demand for renewable energy. The two most commonly used demand-side policies are price-based feed-in tariffs (FiTs) and quantity-based quota obligations (also referred to as renewable portfolio standards [RPS]). Under a FiT scheme, governments set prices often at a premium for different types of renewable power to compensate producers for the higher cost of producing clean energy. Utilities are required to purchase power from renewable resources at this price, but can either spread the additional costs across their entire customer base or receive compensation from the government to recover the incremental costs. Essentially, FiTs work as subsidies to renewable energy to make it cost competitive to fossil fuel based technologies. In contrast, a quota obligation creates a market for tradable green certificates (TGCs), which are awarded to renewable producers based on their renewable energy output. Electricity suppliers must purchase certificates or otherwise supply renewable energy for a certain percentage of their total end-use deliveries. The market value of a TGC thus reflects the balance between the supply of renewable energy and the quantity demanded by the regulation.

Since first introduced in Germany in 1991, FiT schemes have gained greater popularity worldwide. As of early 2012, at least 65 countries have enacted FiT policies, while 18 countries opted for RPS (REN21, 2012). FiTs have for the most part been viewed as successful in terms of deployment: by some estimates, they are responsible for approximately 75 percent of global solar photovoltaic and 45 percent of global wind capacity. However, their record for cost-effectiveness is more inconsistent[1]. In particular, setting the "right"

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[1] In Spain, for example, an overly generous solar FiT resulted in $23 billion subsidy payments and huge power plant-sized installation of photovoltaics. The government had to later reduce the tariff by 45 percent for new solar plants amid budget constraints. Similarly, in Ukraine, the government has introduced a solar FiT at 46 euro cents/kWh, the highest in Europe and more than twice Germany's in 2012. This has prompted concern that tariffs are set higher than necessary and may provide excessive windfall profits for

level of support is difficult. On the one hand, a FiT has to provide sufficient incentives to achieve an overall quantity of renewable generation; on the other hand, it should not be too generous to allow poor performing investment to survive solely based on heavy subsidies. Furthermore, if renewable subsidies are paid by energy consumers, high FiTs may impose an adverse impact on growth and affordability. This is a particular concern to developing countries, where households devote a larger proportion of income to energy and are more vulnerable to rising tariffs.

To understand the cost-effectiveness of existing FiT policies, this paper empirically assesses the responsiveness of renewable investments to various levels of FiT support based on onshore wind development in Europe. We also explicitly account for other policy design features and electricity market conditions that may impose a significant impact on the effectiveness of FiTs. Empirical studies on the cost-effectiveness of FiT schemes have been sparse, partly due to the complexity of the policy design and the lack of comparison data across countries. In our data collection effort, we attempt to rectify the problems by reviewing the detailed design features of wind FiTs in 46 European countries over the period 1991-2010[2]. Because FiT rates often vary by size and location[3], we obtain generator-level wind installation outcomes in order to match wind investment and FiT polices as closely as possible.

Specifically, we estimate a dynamic panel data model to account for (1) autoregressive investment cost shocks, (2) potential correlation among FiT rates, wind installation and unobservable investment costs, and (3) plausible sequential exogeneity of FiT rates - past investment performance affects the current subsidy level. We find no evidence that higher subsidies encourage higher uptake of wind power. The disconnect could indicate the presence of non-economic barriers such as administrative hurdles that worked against financial incentives. It could also suggest a correlation between remuneration and invest-

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investors.

[2] Among the 46 countries, 35 have either adopted FiTs or RPS by 2010, while 11 countries have never enacted any renewable incentive policies during the observation period.

[3] For instance, Greece offers separate rates for mainland vs.island wind installations. Many countries restrict FiTs to installations below a certain size (such as below 20 MW), or have size-specific rates.

ment costs - high remuneration allowed deployment in high-cost locations (with poor wind conditions) or encouraged rent-seeking behavior [4] - both could increase investment costs and reduce the average investment elasticities [5]. After controlling for the cumulative wind electricity generating capacity, we find FiT price has a small but *negative* correlation with wind generation. Because turbine design and the selection of wind location are important determinants of generation efficiency (output per unit of installed capacity), this result suggests that high subsidies provide fewer incentives for investors to avoid high cost sites [6] or engage in innovation activities to enhance turbine efficiency.

In contrast, guaranteed grid access and the duration of FiT contracts are crucial policy characteristics influencing the impact of wind support. Moving from no guaranteed grid access to guaranteed grid access can almost double wind installation in one year, *ceteris paribus*; extending the contract length by an additional one year of an original 5-year agreement will on average increase wind investment by 6 percent annually. The results confirm that investors attach high premiums to the certainty of investment return. A predictable long-term policy commitment is likely to be more effective than excessive short-run fiscal incentives to attract investment.

The organization of the power market also has a sizable impact on the deployment of wind power. If FiT rates are exogenous to electricity prices, higher electricity prices reduce the relative price premium of FiTs, hence the amount of wind investment. But when electricity is traded in a competitive wholesale market, higher electricity prices appear to strengthen the incentive for renewable energy development. This is because many countries allow renewable generators to either sell their electricity at the guaranteed FiTs or sell it in the open exchange. As a result, wholesale competition allows renewable developers to benefit from higher market prices especially during the peak demand.[7] We find that with

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[4] An IEA(2011) study suggests that solar panel sellers price their systems according to the incentive in a given country and try to take a share of any excess remuneration.

[5] An incidence analysis on who benefits from high FiT rates could be an interesting topic for future research.

[6] Good wind locations are unlikely to be exhausted in most countries in the sample as existing wind generation only represents a small percentage of the estimated wind economic potential in these countries.

[7] In Turkey, average electricity price in the wholesale market was higher than FiTs before 2010. As a

the presence of a competitive wholesale market, a one standard deviation increase in an electricity price (3.79 euro cents/kWh) is on average associated with a 38-70 MW increase in wind installation, all other things being equal.

The remainder of the paper proceeds as follows. Section 2 provides a brief review of the existing empirical literature on the effectiveness of renewable incentive policies. Section 3 develops a firm model of capital investment, and identifies the empirical specification and the estimating strategy. Section 4 describes the data. Section 5 presents the results and Section 6 concludes.

2 Literature Review

Empirical analysis on the cost-effectiveness of FiTs has been sparse. A few relevant studies are summarized in this section. The International Energy Agency (IEA) (2008) chooses as an indicator the ratio of annual additional installation of renewable energy and the remaining renewable energy potential to assess the effectiveness of renewable policies in 35 OECD and BRICS countries over the period 2000 to 2005. Comparing the effectiveness indicator against the level of FiTs, the study finds that "beyond some minimum threshold level of 0.07 USD/kWh, higher remuneration levels do not appear to yield greater levels of policy effectiveness". The study is not based on an econometric analysis. It also has not considered the impact of other policy design features, such as mandate grid access and the longevity of purchase contract.

Building upon a similar methodology, IEA (2011) expands the analysis to evaluate the average impact of FiT policies between 2001 and 2009. With the extended observation period, the report finds an inverse correlation between the level of support and the average impact for FiTs (but the result is not statistically significant). The report suggests that the negative correlation may be explained by a learning effect: countries where markets are functioning well and have become mature tend to see both high deployment and low remu-

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result, most of the renewable projects had chosen to sell into the wholesale market. Zhang(2009) explains how electricity market reform has helped the market penetration of renewable energy in Turkey.

nerations. However, the report also admits that rigorous analysis regarding the temporal, dynamic dimension of impact and remuneration adequacy would be required to gain a full understanding of the direction of the causality.

Mulder (2008) analyzes the performance of feed-in systems in stimulating wind power investment in EU15 countries between 1985 and 2005. Mulder finds that Germany, Denmark, and Spain are consistently ranked the top performers measured by annual investment growth rate, total installed capacity, and realizing the full potential of wind resources. All four countries primarily used FiT systems to encourage wind deployment. Since FiTs have never been very high in Germany or Spain, the study concludes that economic incentive is a necessary but not a sufficient condition in achieving widespread renewable energy adoption. Other factors such as a long-term and stable policy environment may be more important determinants.

Söderholm and Klaassen (2007) provide a quantitative analysis of innovation and diffusion in the wind power sector in Denmark, Germany, Spain and the United Kingdom during 1986-2000. Their empirical analysis estimates a simultaneous relationship between FiT rates and the investment cost of wind turbines. On the one hand, higher feed-in prices promote the diffusion of wind technology which in turn encourages learning and cost reduction. On the other hand, high subsidies for wind are associated with lower learning rates - lower cost reduction per doubling of installed capacity. Overall, the authors find the net effect of FiT rates on wind cost ambiguous.

Dong (2012) examines the relative effectiveness of FiT and RPS in promoting wind technology in 53 countries from 2005 to 2009. Consistent with individual country case studies (Astrand and Neij[2006], Butler and Neuhoff[2005] and Río and Gual[2007]), the study identifies a strong correlation between the implementation of FiT policies and development of the wind market. But the analysis treats all FiT policies the same (using a policy dummy variable), it does not examine the impact of heterogenous policy design, including the size of FiT rates.

Overall, no study has systematically examined the cost-effectiveness of existing FiT schemes. In this paper, we intend to fill the gap in the literature by estimating the elasticity of renewable investment to FiT subsidies, while also taking into account other nuanced policy characteristics. We employ a dynamic panel data model and use generalized methods of moments (GMM) to address empirical challenges related to the dynamic correlation among wind installation, investment costs, and FiT remuneration.

3 Model

3.1 Investment Theory

In this section, we develop a simple firm model of capital investment to motivate the empirical specification. Suppose in each period t, the firm chooses the optimal amount of capital K_t (megawatts[MW]) to maximize the expected present value of net cash flows from the invested wind capacity:

$$max \quad V_t = E_t \sum_{t=0}^{N} \beta^t (p_t Q_t) - g_t K_t \tag{1}$$

$$s.t. \;\; Q_t = A_t K_t^{\varpi}$$

where E_t is the expectation sign. $\beta = 1/(1+r)$ is the discount factor, and r is the discount rate. Q_t is the amount of generation and is assumed to be subject to a Cobb-Douglas production function. Wind generation has zero fuel cost and very low operation and maintenance costs (represent about 2.5 percent of the total costs). Almost 75-80 percent of wind production cost is related to upfront investment, including capital expenses on wind turbine, foundations, electrical equipment, grid connection and so on (EWEA, 2012). Therefore, only capital input is included in the production function[8]. ϖ ($\varpi < 1$) is the elasticity of the wind supply curve. Assuming wind resources vary across regions, total wind generation falls off less than linearly with total wind capacity. A_t is the load factor (the average energy output as a percentage of total theoretical capacity) and is mostly determined by the availability of wind (wind speed) and the technical efficiency of wind turbines.

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[8] We also ignore financing cost, which is estimated to be about 1.2 percent of the total cost (EWEA,2012). In section 5, we conduct robustness check by including labor costs in the estimation model.

p_t is the price at which the firm will be paid for wind electricity generation. When FiT policy is in operation, p_t is the guaranteed FiT rate (f_t). When FiT expires, electricity is sold at current market price (e_t). Therefore, $E_t(p_s) = f_t$ if $s \leq N$ and $E_t(p_s) = E_t(e_s) = e_t$, if $s > N$, where N is the length of the guaranteed feed-in contract.[9] g_t is the unit capital investment cost in period t (euro/MW).

Solving the above profit maximization problem, the optimal amount of investment in period t is given by:

$$K_t^* = (\frac{\sum_{t=0}^{N} \beta^t \alpha E(p_t)}{g_t/A_t})^{\frac{1}{1-\varpi}} \tag{2}$$

Taking natural log on both sides of Equation (2) gives:

$$logK_t^* = \frac{1}{1-\varpi}(logB_t + logE_t(p_t) - log(g_t/A_t)) \tag{3}$$

where $B_t = (\sum_{t=0}^{N} \beta^t)/\varpi$.

By aggregating the above equation across firms, one obtains an industry demand function for capital, which is a function of the interest rate (r), the duration of FiT contract(N), the expected remuneration of wind generation ($E_t(p_t)$), and the unit investment cost (g_t/A_t). Due to the correlation with load factor, the unit investment cost is now measured in euro/megawatt hours and is site specific. The lower the wind speed, the higher the cost[10].

Equation (3) implies that firm investment on wind capital is positively correlated with FiT rate through the expected value of the marginal unit of new capital ($E_t(p_t)$). But the positive correlation could be diminished if high FiT rates induce rent-seeking of system suppliers so that any excessive compensation is captured by system suppliers (increase in g_t) or pushing investment to high cost locations (decrease in A_t).

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[9] We assume that electricity prices follow first-order Markov processes and their conditional expectations are given by: $E_t(e_s) = e_t$.

[10] The local wind climate is the most important factor in determining wind investment cost. For example, it is estimated that the cost of wind electricity ranges from approximately 7-10 euro cents/kWh at sites with low average wind speeds to approximately 5-6.5 euro cents/kWh at a wind site with average speeds (EWEA, 2012).

3.2 Basic Econometric Model

Based on Equation (3), a basic empirical model can be described as the following:

$$logK_{it} = \beta_1 logf_{it} + \beta_2 loge_{it} + X_{it}\gamma + T_t + z_t + (v_i + c_{it} + u_{it}) \tag{4}$$

$$c_{it} = \alpha c_{i,t-1} + \epsilon_{it} \qquad |\alpha| < 1 \tag{5}$$

where $logK_{it}$ is the log annual wind capacity additions measured in MW in year t in country i. $logf_{it}$ is the log FiT rate measured in euro cents/kWh. It is the key variable of interest. The coefficient of $logf_{it}$ measures the elasticity of investment with respect to FiT incentives. As shown above, the degree of sensitivity of investment to FiT prices depends on the correlation between FiT and investment costs. A positive correlation between f_{it} and g_t/A_t due to choices of high cost locations or rent-seeking implies low sensitivity (a small/zero coefficient of $logf_{it}$). The extent of non-economic barriers (such as planning delays and restrictions, lack of co-ordination between different authorities, long lead times in obtaining authorizations etc. (IEA, 2008)) also affects the size of the coefficient. If investors in countries with high FiT rates also happen to face higher costs associated with dealing with non-economic barriers, the investment elasticity will be smaller.

$loge_{it}$ is the log of the average electricity price. Ideally, we would want to use annual average wholesale prices. But because wholesale prices are only available for a small set of countries in the sample (IEA, 2012), we use average end-user prices as a proxy.[11] Higher electricity price could encourage renewable deployment if investors take it as a sign of future higher energy demand. On the other hand, if FiT rates are independent from electricity prices, higher electricity prices make current investment in renewable energy less attractive because the relative price premium for renewable electricity becomes lower. There is no prior on the sign of β_2.

X_{it} is a vector of other time-varying variables affecting firm investment decisions. They include (1) N_{it}, the log of the length of guaranteed FiT contract; (2) G_{it}, a dummy variable

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[11] In the robustness check, we restrict the sample to countries where wholesale electricity prices are available and re-estimate the model based on average wholesale prices. We find the basic conclusions do not change with the alternative data.

equals one if there is an interconnection guarantee (both technical requirements and legal procedures) to renewable electricity. The longer the guaranteed FiT support, the lower the uncertainty of investment return over the lifetime of the project. The coefficient of N_{it} is expected to be positive. Similarly, guaranteed grid access reduces investment risk, and the coefficient associated with grid access is likely to be positive.

(3) C_{it} is a dummy variable equal to 1 if a country has either partially or fully developed a competitive electricity wholesale market, and 0 otherwise. The regulatory regime could affect clean energy investment, but the direction of the impact is ambiguous (Heiman, 2006). On the one hand, market competition ensures consumer choice and promotes product differentiation. Consumer demand for "green" energy may boost renewable energy supply. A competitive market is also more friendly to small-scale decentralized power generation as compared to traditional rate-of-return regulation that favors the capital-intensive investment of large central power plants. On the other hand, renewable technologies in general are still more expensive than conventional generation[12]. Without policy support, opening electricity markets to competitive forces might result in less renewable energy development as electricity providers turn to the cheapest source of electricity.

(4) S_{it} is the log of total power output (measured in terawatthours [TWh]) and is an indicative proxy for demand shocks of both domestic and export consumption. The higher the demand for electricity, the more electricity generating capacity including that from renewable sources is likely to be built. The coefficient associated with S_{it} is expected to be positive.

The rapid global development of wind power has had a strong influence on the cost of wind energy over the last 20 years. T_t is a time variable used to capture the common technology trend towards lower costs of the wind industry. We also include year dummies z_t representing year-specific intercepts to account for other common cyclical components. For a dynamic panel data estimation, including common time effects helps reduce the efficiency loss arising from cross section dependence (Phillips and Sul, 2003).

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[12] Especially considering the extra costs on infrastructure required to integrate distributed and intermittent renewable generation.

v_i is a country fixed-effects variable reflecting any time-invariant differences across countries. This may include the natural endowment of wind resources, the initial land availability and public acceptance of wind technology, and any other national renewable energy policies consistently enacted throughout the sample period.

c_{it} is the unit investment cost. Investment costs differ significantly across countries (IEA, 2011) but the cost data are generally not available at a disaggregated level for all countries. Further, investment costs are likely to be serially correlated, as described in Equation (5) where ε_{it} is the stochastic term.

Finally, u_{it} are serially uncorrelated shocks. The error components are in parentheses. Coefficients β_1, β_2, γ and α are parameters to be estimated.

In addition to stimulating investment on wind capacity, a more direct purpose of FiT is to increase actual output of renewable electricity. To assess the direct impact of FiT on wind generation given existing wind capacity, we estimate the following model:

$$logG_{it} = \lambda_1 log\bar{K}_{it} + \lambda_2 logf_{it} + \lambda_3 loge_{it} + X_{it}\vartheta + T_{it} + z_t + (v_i + u_{it}) \tag{6}$$

where G_{it} is the total amount of wind electricity generated (in TWh) in country i for year t. $\bar{K}_{it}$ is the cumulative wind capacity. All other variables are defined in the same way as perviously. λ_1, λ_2, λ_3, and ϑ are parameters to be estimated.

Once a wind project is developed, one would expect investors to maximize production as much as possible because the variable cost is low. Assuming grid access is obtained, the capacity factor of a wind power plant is only determined by wind speed, altitude and turbine efficiency (EWEA, 2012). The hypothesis we want to test is whether higher FiTs affect generation efficiency (output per unit of capacity installed). If generous subsidies allow investment in lousy wind locations to survive, we will expect the coefficient associated with log of FiT rates to be negative. On the other hand, if FiT policies provide incentives for innovation activities aimed at increasing turbine efficiency, the coefficient of log of FiT rates will be positive.

It should be noted that if several countries trade electricity on a common exchange, then renewable incentives in neighboring countries will also affect investment and production in the domestic market. The current models do not capture such a spillover effect.

3.3 Estimating Strategy

In the following, we discuss estimating strategies based on our assumptions of the error term. The number of countries in our unbalanced panel data is 35 (N), and the number of years (T) per country ranges from 1 to 20 with an average of 6.4 years. So we are interested in consistent estimation of the parameters under the premise of small T and large N. If the country-specific effects v_i are correlated with other explanatory variables, which in turn are orthogonal to error components $c_{it} + u_{it}$, then OLS estimation would be biased but a within transformation will yield consistent estimators. However, if the explanatory variables are also correlated with other error components in addition to the correlated country fixed effects, then we would need instrumental variables to purge the endogenous component.

In fact, we suspect the FiT rates are likely to be correlated with the unobserved investment costs. As noted in Söderholm and Klaassen (2007) and IEA(2011), higher FiT remuneration encourages installation in high-cost sites with poor wind resources. In addition, higher subsidies may push up system prices as suppliers along the value chain try to extract excess profits. In both cases, higher FiT rates are correlated with higher investment costs. Higher investment costs would in turn inhibit the ability of the industry to expand wind capacity. Then under the fixed T and large N assumption, both OLS and fixed-effects models yield biased estimation of β_1[13]. Specifically, if $E(f_{it}c_{it}) > 0$ and $E(K_{it}c_{it}) < 0$, a within-estimator would be downward biased.[14]

Due to the autoregressive structure of the investment costs (c_{it}) in the error term, we cannot use lagged values of FiT price in levels as instruments in an equation expressed in first-difference, or lagged first-differences of endogenous variables as instruments for an equation in levels. Blundell and Bond (2000) shows that in a model where explanatory variables are correlated with both fixed effects (v_i) and the error term (c_{it}), and the error

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[13] If T is large, while N is small, then a fixed-effect estimator would be asymptotically unbiased.

[14] The direction of bias of an OLS model also depends on the sign of correlation between f_{it} and v_i.

term is autocorrelated, one can employ a dynamic (common factor) representation which involves α-differencing Equation(4) to partial out the unobserved time-varying variable[15]:

$$\begin{aligned} logK_{it} =& \beta_1 logf_{it} - \alpha\beta_1 logf_{i,t-1} + \beta_2 loge_{it} - \alpha\beta_2 loge_{i,t-1} + X_{it}\gamma - X_{i,t-1}\alpha\gamma \\ & + \alpha logK_{i,t-1} + (z_t - \alpha z_{i,t-1}) + (1-\alpha)v_i + \epsilon_{it} + u_{it} - \alpha u_{i,t-1} \end{aligned} \tag{7}$$

which can be rewritten as:

$$\begin{aligned} logK_{it} =& \rho_1 logf_{it} + \rho_2 logf_{i,t-1} + \rho_3 loge_{it} + \rho_4 loge_{i,t-1} + X_{it}\rho_5 + X_{i,t-1}\rho_6 \\ & + \alpha logK_{i,t-1} + z_t^* + v_i^* + w_{it} \end{aligned} \tag{8}$$

The common factor restrictions are:

$$\rho_2 = -\alpha\rho_1,\ \rho_4 = -\alpha\rho_3 \ and \ \rho_6 = -\alpha\rho_5 \tag{9}$$

If the assumption $\alpha \neq 0$ holds, then Equation (8) can be also interpreted as that the wind capacity expansion exhibits state dependence: the current level of investment depends on investment in last period even after controlling for other variables included in the model.

In the absence of measurement error, the error term w_{it} in Equation (8) is no longer serially correlated after the transformation of the model. One can use difference GMM technique outlined in Arellano and Bond (1991), or system GMM proposed by Arellano and Bover (1995) and Blundell and Bond(1998) to obtain consistent estimators of Equation (8).[16] On the other hand, as we don't expect serially correlated error term in Equation (6), we estimate the determinants of wind generation using a fixed effects model.

One concern arising from the use of GMM estimation of dynamic model (8) is that FiT rates may be sequentially determined, that is there could be feedback from past renewable investment to current values of FiT support. For example, FiTs can be revised downwards when capacity expended and costs of installation reduced. If this is the case, then even though there may not be contemporaneous correlation between w_{it} and f_{it}, f_{it} may still be correlated with $w_{i,t-1}$ in a first-differenced model, i.e. $E(\triangle logf_{it} \triangle w_{it}) \neq 0$. We therefore include $f_{i,t-1}$ and earlier lags as instruments for FiT rates in period t.

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[15] The above equation is obtained by subtracting $\alpha logK_{i,t-1}$ from both sides of Equation(4).

[16] If there are measurement errors and w_{it} follows a $MA(1)$ process, we use K_{is} $(s \geq 3)$ as instruments in the first-differenced equations and $\triangle K_{i,t-s}$ $(s = 3)$ as instruments in the levels equations.

Another potential concern is the endogeneity of electricity price in both static and dynamic equations (6) and (8). Wind power could affect electricity prices through two channels depending on the market structure. First, because wind power normally has a low marginal cost and enters near the bottom of the supply curve, it shifts the supply curve to the right. In general, power prices will be lower during periods with high wind, the so called "merit-order effect". In countries where wind penetration is high, the effect can have a large impact on wholesale prices so that electricity price is correlated with wind installation and generation contemporaneously[17]. Second, using more wind power increases the average costs of production. If FiT subsidies and the costs of interconnecting a wind project to the electric grid are paid by the rate payers, then higher wind generation would lead to higher electricity tariffs.

To deal with the endogeneity of electricity prices, we use the lagged values of $e_{i,t-s}(s \geq 2)$ as the instruments in the difference equation and $(e_{i,t} - e_{i,t-1})$ as the instrument in the levels equation. We also augment the standard GMM estimation with an external instrument - the average industrial natural gas prices. Gas prices constitute a relatively large share of the total cost of gas fired power generation and gas fired power plants tend to be the marginal producer of electricity that sets the market price. The additional instrumental variable from outside the structural equation introduces some exogenous variations in the electricity price, and helps avoid the weak instrument problem that often arises in the GMM estimation (Blundell and Bond (2007) and Bond (2002)). We assess the validity of the external instrument and those from the GMM procedures using standard test of the overidentifying restrictions.

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[17] For example, the reduction in wholesale price due to wind power in Ireland for 2011 is projected to match the premiums that are paid to wind power generators, i.e. wind power support in Ireland is cost neutral(Clifford and Clancy, 2011).

4 Data

We employ an unbalanced panel of 35 European countries where annual wind installation and incentive policies for wind investment are observed during 1991-2010.[18] The information on renewable policy design was obtained mostly from IEA's renewable policy database, and cross-checked with government websites, legislative texts and other related publications. Our review indicates a great deal of variation and complexity over the design of FiT policies[19]. First, FiT rates can be defined very specifically according to the installation location and size. For instance, Greece offers separate rates for mainland vs.island wind installations. Many countries restrict FiTs to installations below a certain size (such as below 20MW), or have size-specific rates. Given the nonuniformity of FiT rates, we collect generator-level wind installation data from a global wind farm dataset[20] to match wind installation with specific policies.

Second, policies sometimes have built-in digression rates so that FiT rates for existing contracts decrease over time. Four countries in our sample, i.e. Austria, France, Germany and Switzerland, offer stepped reductions in tariff for existing contracts but not until at least after 10 years in the contract. For instance, in France, wind tariffs will be reduced by 2 percent annually starting from year 11. We did not specifically estimate the effect of rate digression on current investment, recognizing that ignoring future rate reduction may inflate actual FiT remuneration. However, since price adjustment occurs far into the future, the present value of the price reduction is likely to be small. We also exclude these four countries from the sample for robustness check. The main results do not change.

Third, although in most cases FiT rates are fixed over the contract length (standard FiT), rates can also vary annually according to electricity market price changes or other factors (variable FiT). For example, the first type of FiT enacted in Germany in 1991 involves an energy regulator releasing a new FiT rate each year. Several countries offer a

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[18] The 35 countries include 23 European Union member states, Switzerland, Norway, and 10 countries in Eastern Europe.

[19] See Fischer and Preonas (2012) for a thorough review of the various design of FiT policies.

[20] http://www.thewindpower.net/

fixed premium on top of a (variable) electricity price (premium FiT). They can sometimes be guaranteed for a fixed number of years (as in Denmark, Norway, and Netherlands) or come with no such guarantee (in which case the length of contract will be 0).[21] Because wholesale electricity prices are generally not observed, the final remuneration price under a premium FiT is unobtainable. In the empirical analysis, we restrict samples to standard and variable FiTs, and introduce policy dummy variables to differentiate these two types of policy design.

Finally, four countries in the sample, i.e. Poland, UK, Italy and Sweden opted for a quota obligation scheme facilitated with TGCs to achieve renewable targets[22]. There is a rich literature on the comparison of policy effectiveness of FiT and TGC. Although this is not the focus of this paper, we nonetheless collect data on the annual average certificate prices and estimate the correlation between the value of TGCs and the wind installation results.

It should be noted that in addition to FiTs and TGCs, many countries have enacted additional renewable energy provisions, such as investment tax credits, grants, or VAT exemptions. State and local renewable policies are also prevalent (Fischer and Preonas, 2011). Country fixed-effects will reflect these additional incentives if they are stable across years. However, if additional incentive policies are adjusted according to FiT remuneration levels, then our estimated investment elasticity with respect to the FiT rates will be biased.

Data on annual wind generation are obtained from IEA world energy statistics and balances database. All price variables are deflated by the CPI and are expressed in 2000 prices.

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[21] Spain, Slovenia, and the Czech Republic allow generators to pick between the standard and premium FiTs. In the dataset, the standard FiTs are assumed to be the relevant ones, because these represent the more guaranteed incentive. No definitive reference was found as to which policy wind generators are likely to pick, but a 2008 review of Spanish FiTs (González [2008]) implies that fixed FiTs were the preferred incentive scheme.

[22] Italy has implemented both FiT and TGC since 2008. But no wind installation was observed under FiT. In addition to TGC, UK started implementing a premium FiT in 2010.

4.1 Descriptive Analysis

Table (1) presents summary statistics. The rightmost column reports simple AR(1) specification for the series of variables based on system GMM estimates. All these series are found to be highly persistent, although none appears to have an exact unit root[23]. Figure (1) shows that the number of countries applying FiT policies increased from five in 1991 to 31 in 2010. In comparison, fewer countries opted for RPS/TGC mechanism with just five in 2010.

We divide the sample into different groups based on country-year observation on the status of renewable policy. Table (2) reports the mean value of country characteristics by group. The first three columns of Table (2) reveal statistically significant differences in country characteristics and policy results. Countries with lower wind potential, lower electricity demand, lower electricity and natural gas prices, and no competitive wholesale market are less likely to enact any renewable incentive policies. These countries have seen almost no wind installation. The last three columns of Table (2) further compare the three subcategories of FiT policies. Standard FiT offers the longest contract year. It is also associated with the highest average annual wind installation and generation. These aggregate statistics suggest that (1) renewable policies seem to be effective in stimulating clean energy uptake; (2) multiple factors affect both policy adoption and policy outcome, such as renewable resource endowment, and electricity demand and prices[24]; (3) policy certainty is an important factor affecting the results of renewable development. Standard FiT, Variable FiT and TGC market offer similar levels of annual remuneration to wind projects, but since standard FiT provides the highest degree of certainty over the return to an investment, it is associated with the largest amount of renewable deployment[25].

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[23] A standard difference-GMM estimator will collapse if there is a unit root.

[24] The correlation between market competition and the adoption of renewable policies may simply indicate that the general business environment is more dynamic and receptive to pro-market measures in countries where there is a competitive wholesale market

[25] The theory predicts that quota obligation is more cost-effective in promoting renewable technology, especially those close to commercial stage (such as onshore wind) because it allows competition between providers. Observations in our sample shows that it is more complex in practice. As shown in Table (2),

Figure (2) plots FiT rates against wind capacity installation under standard and variable FiTs. It shows that higher FiT support is not necessarily associated with higher level of wind development. Figure (3) presents cross-country comparison of the average FiT rates and average annual wind installation normalized by a country's (1) per capita GDP, (2) total power generation, and (3) estimated wind technical potential. The figures show large differences in policy impact in countries with similar remuneration levels. Countries that provide very high remuneration sometimes achieved very low penetration levels. Both figures (2) and (3) present suggestive evidence of the lack of connection between FiT remuneration and renewable installation.

5 Empirical Results

5.1 Wind Installation

Table (3) reports various estimators of Equation(8), in which the log of wind installation is the dependent variable. Columns (1) and (2) are estimators of the OLS and fixed-effects models. Columns (3) and (4) report the difference-GMM results, using the log of wind capacity ($logK_{it}$) and electricity prices ($loge_{it}$) lagged 2 to 4 periods in levels, and the log of FiT prices ($logf_{it}$) lagged 1 to 3 periods in levels as instruments; Column (4) introduces an external instrument (natural gas prices in levels) in addition to the standard GMM instruments. Columns (5) and (6) correspond to the system GMM results, where we add the equation in levels with the first-differences of $logK_{it}$ and $logf_{it}$ lagged 1 period and the first-difference of $loge_{it}$ lagged 2 periods as instruments (plus natural gas prices as an exogenous instrument in column (6)). Finally, columns (7) and (8) are OLS and fixed effects estimators of a static model described in Equation(4) (with no instruments). All GMM results are robust one-step estimators.

The coefficient of $logK_{i,t-1}$ is highly significant in all models and justify the adoption

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premium prices for wind in a TGC market does not seem to be lower than FiT subsidies, given the similar level of wind deployment. One explanation for this is that price uncertainty under quota obligations could have driven up certificate prices to compensate for the risk premium.

of a dynamic model. Both OLS and within-group estimators in columns (1) and (2) are inconsistent. The OLS model ignores the country-fixed effects that are correlated with both dependent and explanatory variables. The within results fail to account for the correlation between transformed lagged dependent variable and the transformed error term. Nonetheless, the OLS and within-group estimators provide upper and lower bounds for a candidate consistent estimator of the coefficient of the lagged dependent variable (α) (Bond, 2002). Note that all GMM results on α lie within the boundary of the OLS and within-group estimators. However, the standard first-differenced GMM estimator is found to be very close to within-group results, suggesting weak instrument and potential finite sample bias (Blundell and Bond, 1998). Results of the difference GMM augmented with external instrument are improved. The system GMM are both higher and better determined than both difference GMM estimators. The overidentifying restrictions are valid in all cases. All GMM estimators have also decisively passed the Arellano-Bond test for first- and second-order autocorrelation in the first-difference errors implying that the disturbance term (w_{it}) is first-order serially uncorrelated (with the exception of difference GMM with external instrument in column (4)) and that our moment conditions are valid. The dynamic common factor restrictions are easily accepted in all but the standard difference GMM in column (3). Taken together, we choose system GMM with the external instrument as the preferred results.

Several conclusions emerge from the results. First, the coefficient associated with FiT rates is positive but insignificant, implying that higher FiT rates do not necessarily lead to higher levels of wind installation. This result is stable as we move from one model to another (sign and significance). There are at least two explanations for the lack of strong connection between FiT levels and investment. First, as pointed out in IEA(2011), countries with high remuneration levels may lack the necessary institutional and regulatory environment to attract investment, and fail to scale-up investment due to these non-economic barriers. Another plausible explanation is that overly generous subsidies may have driven up investment costs by allowing (1) inefficient development in less economical sites such as those with low wind speed, and (2) rent-seeking so that any excessive compensation is captured by higher system costs. Note that the coefficients of FiT rates of the static models (columns (7) and (8)) are negative. This downward bias supports the second hypothesis that FiT rates and unobserved investment costs are positively correlated.

Second, the length of FiT contract and guaranteed grid access both have a positive and statistically significant effect on wind capacity growth. On average, a one percent increase in contract length increases annual wind installation by 0.3 percent. Evaluated at the mean level of wind annual installation and mean contract length in the sample, a one standard deviation increase in the length of contract duration increases annual wind installation by 18 percent, or 20MW annually. The effect of grid connection is even more conspicuous. Providing grid access almost doubles wind installation in one year, *ceteris paribus*[26]. Consistent with findings of prior studies (Wiser and Langniss, 2011; Swisher and Porter, 2006), the result suggests that investors attach high premiums to the certainty of investment return. A stable market system that encourages longer-term contracting can often be more cost-effective than those in which short-term trade predominate.

Third, higher electricity prices are correlated with lower investment on wind capacity. However, when we interact electricity price with the dummy variable indicating the existence of a competitive wholesale market, the coefficient associated with the interaction term, as shown in Table (4), is positive and statistically significant. The results hold for all models with the exception of difference GMM with external instrument (column (4) in Table (4)). Based on our preferred system-GMM estimator in column (6) in Table (4), a one percent increase in electricity prices on average leads to a 0.7 percent increase in wind deployment in places served with a competitive wholesale market. This result highlights the importance of electricity market design in renewable development. When FiT rates are independent from electricity price (as in the case of standard FiT and mostly variable FiT), the higher the conventional electricity prices, the lower the relative premiums for renewable electricity, and the less attractive are renewable projects. But in a competitive

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[26] Note that the dummy variable for grid access is dropped in within-group and first-differenced GMM models because it is time-invariant. But the system GMM is able to measure the impact of grid access as it includes the levels equation.

wholesale market, renewable generators can benefit from higher conventional electricity prices by selling directly to the market. As a result, higher electricity prices induce larger amount of renewable investment.

Fourth, total electricity demand proxied by total power generation has a strong positive impact on wind incremental investment. A one percent increase in electricity demand is associated with a 0.7 percent increase in wind installation in the long-run. Coefficients of the trend variable and most of the year dummies (not reported) are also positive and statistically significant.

Fifth, to compare the policy impact of standard FiT, variable FiT and RPS policies, we interact policy dummies with corresponding standard and variable FiT rates, and the average TGC prices respectively. Table (5) reports the results. Different from FiT rates, the TGC prices are more likely to be contemporaneously correlated with wind installation. This is because the price of green certificates is determined by the balance between renewable target and the supply of renewable energy. When renewable target is binding, higher wind penetration is expected to result in lower TGC prices. To explore the causal relationship between TCG price and wind investment, we treat the value of green certificates as endogenous and use lagged variables dated 2 to 4 periods as instruments.

As shown in Table (5), the AR(1) coefficient of wind installation of difference GMM estimator is no longer significant and is in fact outside of the bounds of OLS and within-group estimators. The difference GMM with external instrument performs better suggesting that the external instrumental variable does help to better identify the dynamic equation, however the AR(1) coefficient in column (4) is still only slightly above the within-group estimator. Arellano-Bond test does not reject the null hypothesis of zero autocorrelation in the first-differenced errors at order one in all specifications. The overidentification test supports the validity of instruments. All models except difference GMM (column(3)) pass the common factor restriction tests. As a whole, we continue to prefer results based on the system GMM augmented with external instrument.

With the alternative specification, still we do not detect a strong correlation between FiT remuneration and wind installation - the coefficients associated with FiT rates of either standard or variable FiT policies are positive but insignificant. However, the TGC price does have a statistically significant positive impact on the amount of wind installation. A one percent increase in a TGC price increases wind investment by 1.7 percent on average. All other results are highly consistent with previous estimation.

5.2 Wind Generation

We also examine the relationship between FiT rates and wind output based on specification identified in Equation (6). The econometric results are illustrated in Table (6). Columns (1) and (3) report the fixed effects estimators[27]. Columns (2) and (4) correspond to two-stage least squares (2SLS) estimation using average natural gas prices as instrument for electricity prices. In columns (3) and (4), we also introduce the interactions of policy dummies with FiT rates and TGC prices. Note that despite their being statistically insignificant, the coefficient associated with electricity price is negative in the fixed effects model, and positive in the 2SLS model. The negative correlation between wind generation and electricity price could have contributed to the opposite sign on the endogenous variable. The 2SLS estimators are therefore our preferred results.

Our sixth finding is that after controlling for the total cumulative wind capacity, higher FiT subsidies are not correlated with higher wind generation. In fact, as shown in column(4) of Table (6), a 1 percent increase in a variable FiT is associated with a 1.9 percent reduction in wind generation. The result is statistically significant at 10 percent confidence level. This finding is consistent with the hypothesis that higher financial support induced wind projects in low quality sites with less favorable wind conditions. Consequently, the wind generation becomes lower given the same level of wind capacity.

5.3 Robustness Check

First, as pointed out by IEA(2011), it is possible that the growth of renewable is initially constrained as the supply chain is put in place and administrative systems are streamlined. Capacity then grows more quickly as the local industry matures and regulators become

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[27] A Hausman test decisively rejects random effects model at any level of significance.

more experienced. To measure the learning effects, we introduce an additional regressor that measures the number of years a FiT policy had been put in place in a given country. We find introducing the measurement of policy implementation horizon has very little impact on the results.

Second, although labor costs are only a small component of the overall production costs, it may still affect FiT compensation scale and investment decisions. If labor costs are correlated with both FiT support and wind installation, the elasticity of FiT price will be underestimated. To explore how important is such an effect, we use the average employee cost in electricity generation sector (NACE 3511) reported in AMADEUS database maintained by Bureau Van Dijk as an approximation for labor cost of wind generation. Introducing the additional variable further reduces the sample size, but the basic results do not change.

The preceding results are also robust to alternative specifications assuming FiT remuneration as strictly exogenous, or using instruments for wind installation lagged three periods and earlier to account for possible MA(1) measurement errors.

6 Conclusion

FiTs are rapidly emerging as the most widely used policy instrument to promote renewable energy deployment in the world. Meanwhile, the cost impacts of FiT policies have become a primary concern for policy makers, and particularly so in developing countries. Whether the costs are recovered from ratepayers or taxpayers, rising costs can create both political and economic pressures. Households in developing countries are particularly vulnerable to increase in energy prices because energy comprises a higher share of their income than those in developed countries.

While there exists a large literature on the review of FiT design, empirical studies on the cost-effectiveness of FiT policies are scarce. This paper adds to the literature by estimating the sensitivity of renewable investment to FiT remuneration levels based on wind data of 35 European countries between 1991 and 2010. Understanding the relation between tariff setting and policy outcome is important not only because it is a critical step to examine the cost-effectiveness of the existing policy design but also it can provide useful lessons for countries who are contemplating adopting FiT programs.

The performance of a FiT policy can be judged by its impact on a number of parameters, i.e. installed capacity, energy production, improved energy security, greenhouse gas reduction and other environmental benefits, as well as economic development opportunities. In this paper, we assess policy performance based on its impact on annual wind capacity installation and generation. Our analysis shows that although FiTs have worked to spur investment, high remuneration levels have not necessarily yielded greater levels of installation. We conjecture that non-economic barriers and the negative correlation between investment costs and FiT rates could contribute to the weak correlation between incentives and investment. Countries providing high incentives may happen to be the ones that have very high levels of non-economic barriers. Excessive subsidies could also provide rent-seeking opportunities or allow investment in high cost sites.

On the contrary, FiT contract duration and interconnection guarantee are important determinants of the "shadow price" of FiT support - longer contracts and guaranteed grid access have induced larger deployment. Because both features are crucial to investor confidence in long-term market security, the results suggest that policy certainty is just as important, if not more than, short-run financial incentives to attract private participation. Our results also show that the overall electricity market design matters. A competitive market tends to be more conducive to renewable deployment.

Finally, we show that given cumulative capacity installation, variable FiT rates are negatively correlated with wind generation. Since wind capacity factor is largely determined by local wind speed, higher financial incentives could have pushed investment to locations with less favorable wind conditions. Overall, our analysis provides preliminary evidence of the dynamic correlation between investment costs and FiT support levels. More in-depth incidence analysis on who benefits from high FiT rates can be an interesting topic for future research.

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Table 1: Summary Statistics

Variable	**Obs**	**Mean**	**Std. Dev.**	**Within S.D.**	**Min**	**Max**	**AR(1) SYS GMM**
Annual wind installation (MW)	740	110.63	369.26	202.09	0	3247	0.736
							(0.068)
Annual wind generation (TWh)	653	1.25	4.49	2.51	0	38.55	0.913
							(0.024)
FiT rate (euro cents/kWh)	270	6.94	2.62	0.80	1.10	24.11	0.805
							(0.086)
TGC price (euro cents/kWh)	29	6.03	2.59	0.86	1.66	11.57	
FiT contract length (years)	294	11.52	6.73	4.76	0	25	0.913
							(0.028)
Grid access	301	0.91	0.29	0.3	0	1	1
							(0.024)
Avg. end-use electricity price (euro cents/kWh)	473	7.72	3.79	1.3	0.89	25.21	0.922
							(0.025)
Avg. industrial natural gas price (euro/GJ)	333	5.09	1.83		0.98	12.02	0.651
							(0.054)
Total electricity output (TWh)	683	100.00	133.28	13.41	1.95	594.69	0.981
							(0.010)
Wind power potential (TWh)	575	1611.14	1607.34	0	42.29	5279.59	1
Competitive wholesale market (0/1)	740	0.32	0.47	0.3	0	1	0.946
							(0.008)

Table 2: Country Characteristics by Policy Type

Variable	Average FiT	TGC	No Policy	Standard FiT	Variable FiT	Premium FiT
Annual wind installation (MW)	301	298	3.33***	325	102.60	85.86
	(221.81)	(326.3)	(22.9)	(688)	(227.68)	(125.15)
Annual wind generation (TWh)	2.73	1.93	0.024***	4.16	0.71	1.89
	(6.70)	(2.11)	(0.18)	(8.83)	(1.35)	(2.19)
FiT rate / TGC price (euro cents/kWh)	6.67	6.03	-	6.69	6.62	4.22
	(2.75)	(2.59)		(3.04)	(1.84)	(2.37)
FiT contract length (years)	11.52	-	-	14.01	9.07	6.88
	(6.73)			(4.78)	(6.24)	(9.03)
Grid access	0.91	-	-	0.99	1	0.5
	(0.29)			(0.13)	(0)	(0.51)
Avg. end-use electricity price (euro cents/kWh)	7.88	9.04	5.74***	7.79	7.86	8.23
	(3.29)	(3.86)	(4.49)	(3.23)	(4.07)	(1.17)
Avg. industrial natural gas price (euro/GJ)	5.32	5.74	4.5***	5.61	4.97	4.9
	(1.74)	(2.38)	(1.64)	(2.02)	(1.22)	(1.23)
Total electricity output (TWh)	119.65	217.15	48.9***	152	88.04	70.46
	(166.5)	(107.2)	(67.1)	(191)	(148.44)	(49.93)
Wind power potential (TWh)	1433	3021	1156.4***	1522	1042	1836
	(1553)	(1719)	(1241.9)	(1701)	(1062)	(1664)
Competitive wholesale market (0/1)	0.51	0.73	0.06***	0.58	0.24	0.77
	(0.50)	(0.45)	(0.24)	(0.49)	(0.43)	(0.42)
Obs.	301	41	545	165	88	48

Note: Obs. is the number of observations of annual wind installation.“No policy” includes 9 countries that have never implemented wind incentive policies during the sample period. Ideally, we would only include these countries in the last column. But data on wind potential, electricity and natural gas prices are not available for most of these countries. - indicates that the numbers are not available. *** indicates the difference between “No Policy” and “Average FiT”is statistically significant at 1% level. For comparison among FiT, *** indicates the difference between “Variable FiT” or “Premium FiT” and “Standard FiT” is statistically significant at 1% level, ** indicates significance at 5%, and * indicates significance at 10%.

Table 3: Determinants of Log of Annual Wind Installation (I)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	Within Group	DIF GMM	DIF GMM	SYS GMM	SYS GMM	Static	Static
				+ external IV		+ external IV	OLS	Within Group
Lagged wind installation	0.800***	0.360**	0.380***	0.488***	0.583***	0.635***		
	(0.0595)	(0.133)	(0.120)	(0.166)	(0.071)	(0.077)		
Log FiT rates	0.0298	0.803	1.396	1.612	0.388	0.620	-0.096	-0.509
	(1.370)	(1.504)	(1.423)	(1.372)	(1.129)	(0.900)	(0.604)	(2.156)
Lagged log Fit rates	-0.312	1.428	1.828*	0.889	0.647	0.200		
	(1.310)	(1.437)	(1.101)	(1.088)	(0.961)	(0.918)		
Competitive market	-0.699	-0.462	-0.492	-0.386	-0.530	-0.589	0.532	0.866
	(0.508)	(0.358)	(0.299)	(0.716)	(0.386)	(0.764)	(0.533)	(0.588)
lagged Competitive market	0.941**	1.269***	1.297***	0.532	1.582***	0.708		
	(0.462)	(0.419)	(0.377)	(0.604)	(0.515)	(0.442)		
Log electricity price	-1.047	-2.509**	-2.858***	-2.564*	-0.935	-2.840**	0.878*	-4.477**
	(0.931)	(0.954)	(0.836)	(1.368)	(1.010)	(1.327)	(0.520)	(2.051)
lagged log electricity price	0.558	-2.518	-2.712*	0.533	-0.238	1.911		
	(0.900)	(1.719)	(1.415)	(1.128)	(1.256)	(1.212)		
Log power output	3.051**	3.909**	4.217***	6.179***	3.464***	4.517**	0.941***	-2.184
	(1.517)	(1.608)	(1.391)	(1.862)	(0.951)	(1.803)	(0.178)	(2.950)
lagged log power output	-2.936*	-0.276	-0.677	0.115	-3.280***	-4.263**		
	(1.491)	(2.361)	(2.244)	(1.390)	(0.945)	(1.819)		
Log contract year	1.137	0.733	1.561	2.778*	1.96	2.264**	0.398	-2.188
	(1.700)	(1.144)	(1.552)	(1.653)	(1.460)	(0.946)	(0.890)	(1.930)
Lagged log contract year	-0.473	-0.893	-0.316	-1.911	-1.856	-2.161***		
	(1.362)	(0.903)	(0.883)	(1.281)	(1.309)	(0.790)		
Guaranteed grid access	1.387***	-	-	-	1.417	1.801**	1.032	-
	(0.270)				(1.284)	(0.708)	(0.657)	
Time trend	0.137***	0.0875	0.112*	0.150*	0.0919**	0.151***	0.300***	0.169**
	(0.0516)	(0.0665)	-0.0649	-0.0902	(0.0357)	(0.038)	(0.070)	(0.075)
R-squared	0.863	0.771					0.496	0.565
Obs.	100	100	77	54	100	70	128	128
first-differenced errors m1: p-value			0.0098	0.0099	0.0052	0.0198		
first-differenced errors m2: p-value			0.3999	0.0782	0.8992	0.3790		
Sargan test: p-value			0.5018	0.4667	0.8943	0.9912		
Common factor restiction: p-value			0.0074	0.4362	0.2179	0.3584		

Note: Columns (1) and (2) report results from estimating determinants of annual wind installation identified in equation (8) via OLS and fixed effects model. Columns (3) and (4) report the difference-GMM results, using the log of wind capacity ($logK_{it}$) and electricity prices (e_{it}) lagged 2 to 4 periods in levels, and FiT prices (f_{it}) lagged 1 to 3 periods in levels as instrument; Columns (5) and (6) corresponds to the system-GMM results, where equation in levels is instrumented with the first-differenced $logK_{it}$ and f_{it} lagged 1 period, first-differenced e_{it} lagged 2 periods. Average natural gas prices are used as an exogenous instrument in columns (4) and (6). Columns (7) and (8) are OLS and fixed effects estimators of Equation(4) with no instruments. Standard error adjusted for clustering on country are reported in parentheses. *** indicates significant at 1% level, **indicates significant at 5% level, *indicates significant at 10% level. Reported R^2 is the adjusted R^2 for OLS and fixed effects model.

Table 4: Determinants of Log of Annual Wind Installation (II)

	(1) OLS	(2) Within Group	(3) DIF GMM	(4) DIF GMM + external IV	(5) SYS GMM	(6) SYS GMM + external IV	(7) Static OLS	(8) Static Within
Lagged wind installation	0.776***	0.329**	0.326**	0.419***	0.596***	0.596***		
	(0.0590)	(0.139)	(0.137)	(0.158)	(0.0716)	(0.0713)		
Log FiT rates	-0.15	0.385	0.581	1.431	-0.116	0.209	0.414	0.00481
	(1.218)	(1.394)	(1.215)	(0.970)	(1.008)	(0.890)	(1.607)	(0.497)
Lagged log Fit rates	-0.294	1.189	1.226	0.129	0.106	-0.115		
	(1.202)	(1.212)	(1.031)	(1.181)	(1.067)	(0.922)		
Competitive market*Log electricity price	-0.254	-0.0729	-0.079	-0.164	-0.166	-0.110	0.312	0.344
	(0.244)	(0.167)	(0.144)	(0.233)	(0.199)	(0.270)	(0.251)	(0.238)
Competitive market*lagged log electricity price	0.333	0.429**	0.398**	0.0412	0.506***	0.302**		
	(0.221)	(0.183)	(0.179)	(0.147)	(0.173)	(0.139)		
Log electricity price	-1.02	-2.807**	-2.930***	-1.834	-1.267	-2.596***	-4.630**	0.486
	(0.856)	(0.995)	(0.915)	(1.201)	(1.189)	(0.867)	(2.191)	(0.468)
Lagged log electricity price	0.846	-2.503	-2.515*	1.133	0.876	2.301**		
	(0.910)	(1.663)	(1.439)	(0.844)	(1.218)	(0.900)		
Log power output	2.540*	2.979**	2.983**	5.535***	2.044	3.173***	-1.731	0.918***
	(1.504)	(1.358)	(1.346)	(1.431)	(1.444)	(1.075)	(3.015)	(0.153)
Lagged log power output	-2.326	-0.375	-0.531	-0.113	-1.808	-2.818***		
	(1.475)	(2.110)	(2.148)	(1.024)	(1.424)	(1.060)		
Log contract year	1.065	0.495	0.552	2.066**	1.362	2.847***	-1.849	-0.406
	(1.633)	(1.257)	(1.543)	(0.992)	(1.746)	(1.033)	(1.556)	(0.760)
Lagged log contract year	-0.743	-1.198	-1.045	-2.955**	-1.487	-2.722**		
	(1.336)	(0.744)	(0.779)	(1.373)	(1.647)	(1.047)		
Guranteed grid access	1.488***				2.610*	2.476***		1.076
	(0.269)				(1.388)	(0.841)		(0.685)
Time trend	0.157***	0.103	0.118	0.199***	0.146**	0.181***	0.184**	0.283***
	-0.0484	(0.0694)	(0.0723)	(0.0767)	(0.0716)	(0.0327)	(0.0814)	(0.0674)
R-squared	0.85	0.746					0.54	0.498
Obs.	107	107	82	59	107	77	138	138
first-differenced errors m1: p-value			0.0089	0.0078	0.0047	0.0103		
first-differenced errors m2: p-value			0.1764	0.2701	0.4427	0.5019		
Sargan test: p-value			0.4867	0.5059	0.7076	0.9766		
Common factor restiction: p-value			0.0406	0.7053	0.9801	0.1598		

Note: Columns (1) and (2) report results from estimating determinants of annual wind installation identified in equation (8) via OLS and fixed effects model. Columns (3) and (4) report the difference-GMM results, using the log of wind capacity ($logK_{it}$) and electricity prices (e_{it}) lagged 2 to 4 periods in levels, and FiT prices (f_{it}) lagged 1 to 3 periods in levels as instrument; Columns (5) and (6) corresponds to the system-GMM results, where equation in levels is instrumented with the first-differenced $logK_{it}$ and f_{it} lagged 1 period, first-differenced e_{it} lagged 2 periods. Average natural gas prices are used as an exogenous instrument in columns (4) and (6). Columns (7) and (8) are OLS and fixed effects estimators of Equation(4) with no instruments. Standard error adjusted for clustering on country are reported in parentheses. *** indicates significant at 1% level, **indicates significant at 5% level, *indicates significant at 10% level. Reported R^2 is the adjusted R^2 for OLS and fixed effects model.

Table 5: Determinants of Log of Annual Wind Installation (III)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	Within Group	DIF GMM	DIF GMM + external IV	SYS GMM	SYS GMM + external IV	Static OLS	Static Within
Lagged wind installation	0.779***	0.231	0.227	0.381**	0.597***	0.632***		
	(0.0596)	(0.154)	(0.138)	(0.188)	(0.0622)	(0.0675)		
Log FiT rates * Standard FiT	-0.0546	-0.813	-0.385	0.992	-0.260	0.576	-0.222	-2.518
	(1.380)	(1.591)	(1.526)	(1.284)	(1.133)	(0.959)	(0.538)	(2.167)
Lagged log Fit rates * Standard FiT	-0.416	0.623	0.627	0.0439	0.595	-0.278		
	(1.326)	(1.307)	(1.030)	(1.415)	(1.009)	(1.087)		
Log FiT rates* Variable FiT	1.908	5.430*	5.639**	2.013	0.991	0.0473	0.258	5.894***
	(2.582)	(2.964)	(2.674)	(1.636)	(1.940)	(1.497)	(0.516)	(1.368)
Lagged log FiT rates* Variable FiT	-2.185	2.035	2.885	2.502**	-0.597	0.398		
	(2.478)	(2.650)	(2.422)	(1.266)	(1.759)	(1.096)		
Log TGC price * RPS	-1.507	-2.505	-3.027	-1.765	-5.240**	-4.247**	-0.234	2.490*
	(3.540)	(1.817)	(1.996)	(3.723)	(2.242)	(2.066)	(0.543)	(1.377)
Lagged log TGC price* RPS	1.495	2.581	2.531	1.109	6.126**	4.863*		
	(3.706)	(3.275)	(3.019)	(4.488)	(2.778)	(2.532)		
Competitive market	-0.517	-0.118	-0.145	-0.131	-0.355	-0.0318	0.604	0.895
	(0.524)	(0.361)	(0.317)	(0.537)	(0.446)	(0.752)	(0.528)	(0.571)
Lagged Competitive market	0.898*	1.338***	1.434***	0.506	1.189**	0.538		
	(0.479)	(0.424)	(0.397)	(0.382)	(0.457)	(0.374)		
Log electricity price	-1.335	-4.031***	-4.466***	-3.016**	-1.791**	-3.066***	0.677	-4.823**
	(0.843)	(1.000)	(0.869)	(1.267)	(0.788)	(0.992)	(0.509)	(1.865)
lagged log electricity price	0.832	-2.851*	-3.047**	0.772	1.188	2.496**		
	(0.811)	(1.653)	(1.411)	(1.083)	(0.917)	(1.208)		
Log power output	3.059*	3.794**	3.608***	5.637***	3.281***	3.295*	0.976***	-1.555
	(1.584)	(1.599)	(1.280)	(1.719)	(1.046)	(1.780)	(0.176)	(2.752)
lagged log power output	-2.923*	0.378	-0.169	0.581	-3.151***	-3.070*		
	(1.566)	(2.155)	(1.842)	(1.182)	(1.006)	(1.748)		
Log contract year	1.281	-1.041	-0.194	2.286	1.039	2.643**	0.326	-3.794*
	(1.875)	(1.840)	(2.044)	(1.676)	(1.487)	(1.136)	(1.004)	(1.954)
Lagged log contract year	-0.244	-1.08	-0.797	-2.858*	-0.43	-2.487**		
	(1.580)	(1.048)	(0.818)	(1.540)	(1.224)	(0.975)		
Guaranted grid access	1.323***				1.449	1.578*	0.91	
	(0.294)				(1.377)	(0.862)	(0.700)	
Time trend	0.146***	0.0587	0.0955*	0.163**	0.141***	0.147***		
	(0.0526)	(0.0651)	(0.0554)	(0.0804)	(0.0299)	(0.0347)		
R-squared	0.859	0.776						
Obs.	107	107	82	59	107	77	138	138
first-differenced errors m1: p-value			0.014	0.0071	0.0053	0.0143		
first-differenced errors m2: p-value			0.2171	0.2194	0.4317	0.7735		
Sargan test: p-value			0.6002	0.5194	0.9751	0.9975		
Common factor restriction: p-value			0.0003	0.9606	0.5611	0.7907		

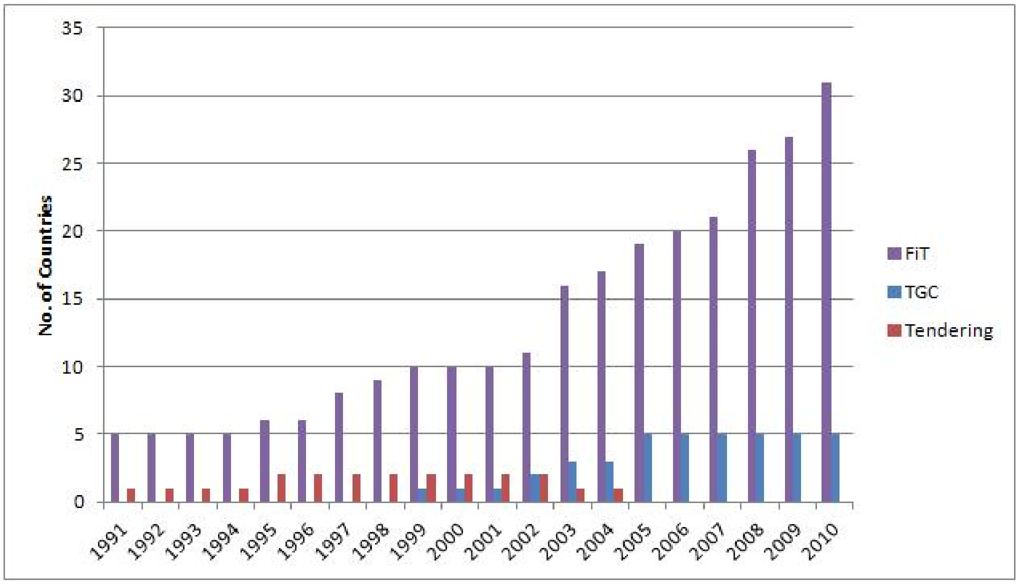
Note: Columns (1) and (2) report results from estimating determinants of annual wind installation identified in equation (8) via OLS and fixed effects model. Columns (3) and (4) report the difference-GMM results, using the log of wind capacity ($logK_{it}$) and electricity prices (e_{it}) lagged 2 to 4 periods in levels, and FiT prices (f_{it}) lagged 1 to 3 periods in levels as instrument; Columns (5) and (6) corresponds to the system-GMM results, where equation in levels is instrumented with the first-differenced $logK_{it}$ and f_{it} lagged 1 period, first-differenced e_{it} lagged 2 periods. Average natural gas prices are used as an exogenous instrument in columns (4) and (6). Columns (7) and (8) are OLS and fixed effects estimators of Equation(4) with no instruments. Standard error adjusted for clustering on country are reported in parentheses. *** indicates significant at 1% level, **indicates significant at 5% level, *indicates significant at 10% level. Reported R^2 is the adjusted R^2 for OLS and fixed effects model.

Table 6: Determinants of Log of Wind Generation

	(1)	(2)	(3)	(4)
	Within Group	Within Group + IV	Within Group	Within Group + IV
Log of total wind capacity	0.859***	0.965***	0.879***	0.956***
	(0.0464)	(0.0897)	(0.0381)	(0.0664)
Log of FiT rates	-0.317	-0.423		
	(0.303)	(0.493)		
Log of FiT rates * standard FiT			-0.00127	-0.247
			(0.41)	(0.365)
Log of FiT rates * variable FiT			-0.955***	-1.903*
			(0.150)	(1.134)
Log of TGC price * RPS			-0.360*	-1.06
			(0.181)	(0.727)
Competitive market	-0.0338	0.191	-0.0569	0.183*
	(0.0810)	(0.160)	(0.0809)	(0.0971)
Log of electricity price	-0.093	5.396	-0.00541	3.907
	(0.171)	(6.209)	(0.166)	(4.051)
Log of contract year	-0.262*	-0.302	-0.051	-0.139
	(0.137)	(0.482)	(0.196)	(0.426)
Time Trend	0.0945***	-0.459	0.0773***	-0.371
	(0.0213)	(0.443)	(0.0153)	(0.294)
R2	0.843	0.929	0.805	0.955
Obs.	136	87	145	96

Note: Columns (1) and (3) report the determinants of log of wind generation identified in Equation (6) using fixed effects models. Columns (2) and (4) correspond to two-stage least squares (2SLS) estimation using average natural gas prices as instrument for electricity prices. Standard error adjusted for clustering on country are reported in parentheses. *** indicates significant at 1% level, **indicates significant at 5% level, *indicates significant at 10% level. Reported R^2 is the adjusted R^2 for fixed effects model.

Figure 1 Number of Countries by policy - More countries have adopted FiT policies



Note: UK in 2010 implemented both FiT and RPS. This graph reports the total number of countries implementing FiT, RPS and competitive bidding policies in each year. Under a competitive bidding system, contracts for renewable projects are offered to the lowest bid first, followed by the next cheapest bid, and so on, until the required renewable capacity target is reached.

Figure 2 Wind installation by FiT rates

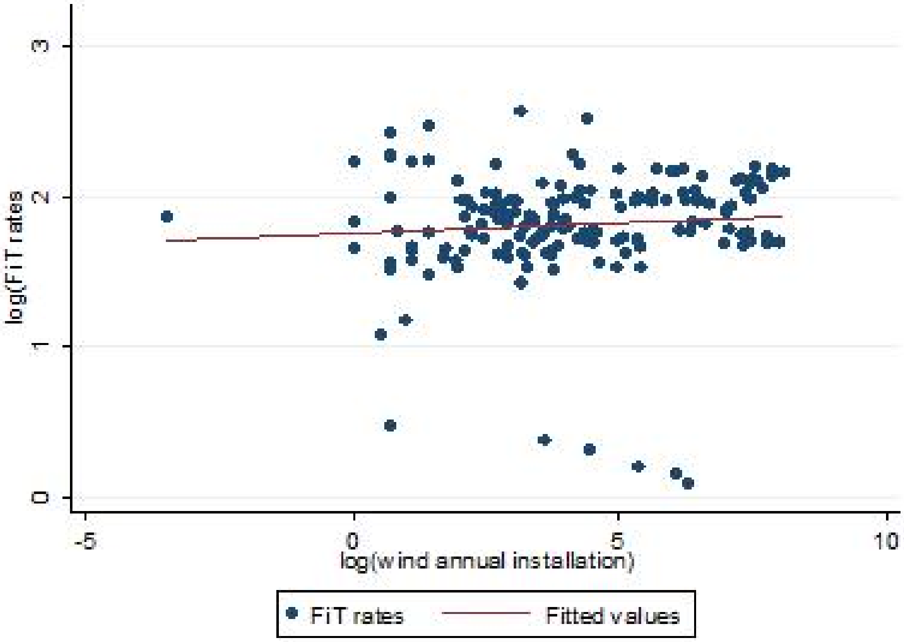


FIGURE 3 WIND INSTALLATION V.S. FIT AND RPS PRICES