RENEWABLE ENERGY AT WHAT COST?

Assessing the Effect of Feed-In Tariff Policies on Consumer Electricity Prices in the European Union

By Christopher A. Klein, MA (Hons)

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ABSTRACT

In the last two decades, feed-in tariffs (FIT) have emerged as the dominant policy instrument for supporting electricity from renewable sources in the European Union. This paper examines the effect of such feed-in tariffs on consumer prices for electricity. While a multitude of studies examine the effects of FIT policies on electricity prices within individual countries or across countries using complicated ex-post computer simulations, there are a dearth of rigorous ex-post, cross-country econometric analyses. Using 1992-2009 panel data across 20 European countries and a dynamic panel data model estimation, this paper analyzes the effect of FIT policies for electricity generated from wind and solar photovoltaic (PV) on electricity prices at the household consumer level. The analysis finds a mild association of the support level for wind energy with higher retail prices, but no price increase for solar PV support. This finding points toward the existence of a "merit-order effect" and, in particular, a strong "time-of-day" effect, where solar PV is able to replace more costly natural gas and petroleum generation because it is generated during times of peak demand, whereas electricity from wind is mostly generated at night when demand is low. However, the shares of solar PV electricity generated under the FIT are still very low; as the share of electricity generation that is covered by the FIT rises, adverse price effects may become more apparent. This paper also finds that feed-in tariffs for wind only increase retail prices in the presence of retail regulation, indicating that regulatory bodies may allow utility companies to charge higher prices in the presence of FIT payments, whereas utility companies that are subject to retail competition are not able to pass on their additional costs to customers. In addition, the paper further finds that larger shares of electricity generated from hydro and nuclear power decrease retail rates, suggesting that, due to their similar cost profile, the same could be true for wind and solar PV in the long term, once a fleet of generation capacity from wind and solar PV is established and the initial capital costs are recovered.

I. INTRODUCTION

The current consensus among European policymakers is that well-designed feed-in tariff (FIT) schemes are the most effective way of achieving the development of electricity-generating capacity from renewable sources (RES-E). This differentiates Europe from the United States, where Renewable Portfolio Standards have been the dominant RES-E support instrument. The European view is driven by the success of FIT policies in deploying renewable energy in Germany, Denmark, and Spain, among other countries, and is supported by a large body of academic evidence (EC 2008; OPTRES 2007; Lipp 2007; Butler and Neuhoff 2008; Lesser and Xu 2008; Alagappan, Orans, and Woo 2011). While unable to prescribe policy instruments to member states, the European Commission concluded in a 2008 communication to the European Parliament (EP) and European Council (EC) that FITs "achieve greater renewable energy penetration, and do so at lower costs for consumers" (EC 2008).

The success of FIT policies can largely be traced to the high level of security that FIT schemes provide for investors in RES-E generation. They are energy-supply policies that (1) impose obligations on utilities and grid operators to purchase the full output generated by qualifying renewable energy generators, (2) guarantee an above-market payment per unit output ($/kWh) for the full output of the system, (3) limit these special payments to a specified time period, and (4) differentiate payments between projects based on technology type, project size, the quality of the resource, or other project-specific variables. FITs thus mitigate future electricity market volatility, making it very likely that investors will recover large up-front capital investments (Butler and Neuhoff 2008; Lesser and Xu 2008). Since 1990, 24 EU member states have introduced FIT policies.[1] Over this time period, RES-E generation capacity in the EU-27 countries has developed rapidly, especially in those countries with established FIT programs (See Figure 1).

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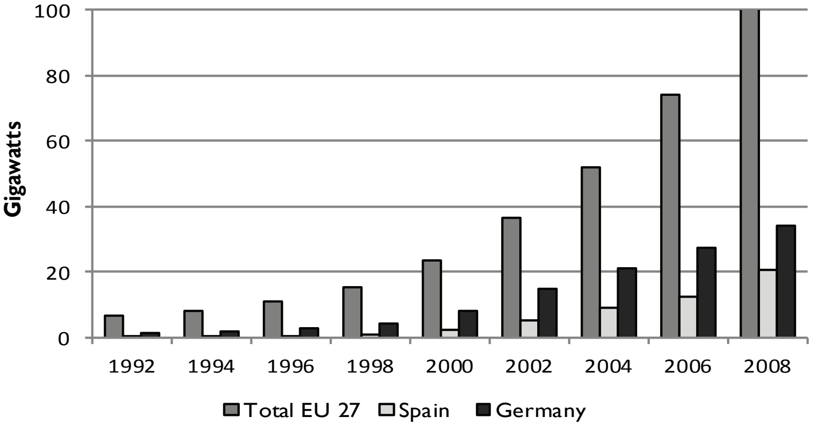
[1] Only Sweden, Poland, and Romania continue to rely solely on minimum quota regulations to achieve their EU targets.

Figure 1. Total Non-Hydroelectric RES-E Electricity Generation Capacity in the EU 27, Germany, and Spain



Although many scholars have conceded that FIT policies are the most effective way to promote RES-E (EC 2008; RES-financing 2011; OPTRES 2007), the increase in the share of RES-E in the electricity production mix has spurred debate about the cost of such policies. As FIT payments are normally above the spot-market price for electricity, policy makers are concerned with the effects FIT schemes may have on electricity prices and, subsequently, the competitiveness of European economies, inflation levels, and social welfare. Rising electricity costs were less of a concern when renewable energy targets were relatively low; however, as EU targets for RES-E generation have grown so has apprehension about rising electricity prices. Some countries have already responded to these concerns. Germany recently reduced its FIT payments for solar photovoltaic (PV) by 15 percent for the year 2012, while Spain retroactively cut its solar PV FIT program by up to €3 billion (BMU 2011; Mallet 2010).

There has not been a cross-country, ex-post econometric study of the negative effects of FIT regimes on consumer prices. In light of this dearth, this paper aims to illuminate the current debate on adverse economic effects of renewable energy promotion—in particular, feed-in tariffs—in EU member states. It provides a rigorous ex-post econometric analysis of the effect of technology-specific FIT legislations for wind and solar PV on electricity prices at the household consumer level across 20 European countries between 1992 and 2009.

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II. CONCEPTUAL FRAMEWORK & REVIEW OF THE LITERATURE

Like other network utilities, the electricity sector is characterized by extremely high up-front (i.e. fixed) capital costs, with considerably lower variable costs (Newberry 1999; Stoft 2002). Fixed costs reflect the capital necessary to build and maintain physical infrastructure such as generation facilities or high-voltage transmission networks. The structural costs for building generation facilities vary largely between countries. In particular, fixed costs depend on the differential between a country's average and peak electricity demand; the more extreme a country's electricity demand, the higher its fixed costs will be. Other factors affecting electricity costs include the cost of labor, the ability to obtain necessary permits, the cost and availability of financing, and geographic factors such as population density and distance between generation and demand centers. Unless they are subsidized or cross-subsidized from other sectors, household electricity prices generally allow investors in generation capacity to recover these capital costs (Newberry 1999).

In addition to the fixed costs, utility companies are faced with variable input costs for generating and supplying electricity. First and foremost among those are the variable costs of generating electricity, which companies pay in the form of wholesale prices, supply contracts, or as direct inputs in cases where they still have generation capacity of their own. These costs include the input costs for fossil fuels as well as labor costs required for operating power plants (Newberry 1999). Typically, the power portfolio is made up of different power suppliers, generating electricity through different technologies. The use of each generator depends on the amount of power it can supply at a certain price, and generators compete on the basis of the marginal (variable) cost of the plant. This is called "merit order," where different plants are ranked from low marginal cost (e.g. hydro) to high marginal cost (e.g. natural gas) (Fox-Penner 1997; Newberry 1999). In liberalized power markets, the wholesale price for electricity is thus determined by the marginal technology used. As most European electricity markets are only partially restructured, it is assumed that their operational decisions are determined by producers' variable costs as they would be in a liberalized wholesale market.

Within this framework, FITs increase utility companies' variable costs as they oblige companies to take off electricity generated by renewable producers at a pre-determined price (the fixed tariff) that is typically above the average spot-market price. This is in contrast to the logic of a wholesale market price determined by variable costs, as renewable generators are characterized by virtually zero variable cost. Therefore, it can be assumed that the obligation to pay feed-in tariffs to renewable generators raises companies' generation costs in the short-term, which they then likely pass on to consumers.

Numerous ex-ante studies estimate the additional costs of generating large shares of electricity from renewable resources. A 2011 study estimates the total cost of RES support in 2009 at the EU level to amount to approximately €35 billion (RES-Financing 2011). Additionally, for Germany alone, Frondel et al. (2008) calculate the discounted total net cost of subsidizing electricity production from wind and solar PV to be €20.5 billion and €53.3 billion respectively, for generators installed between 2000 and 2010. According to their account, German households paid a price mark-up due to the subsidization of green electricity of about 1.5 cent per kWh in 2008, amounting to about 7.5 percent of average household electricity prices.

In 2007, OPTRES predicted that a steady rise in average EU consumer prices for electricity was necessary to finance RES-E deployment over the next 10 years, foreseeing an increase from 2.1 €/MWh in 2005 to a rate between 5.0 €/MWh and 7.7 €/MWh for the period 2005 to 2020. Using a quantitative electricity market model that accounts for factors such as oligopolistic behavior, emission trading, and restricted cross-border transmission capacities, Traber and Kemfert (2009) also find an upward price effect of the German FIT.

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Among the relatively few ex-post studies that have analyzed the price effects of FIT policies, Gual and del Rio (2007) assess the effect of the Spanish FIT between 1999 and 2003 in terms of additional costs paid by the consumer for renewable compared to conventional electricity (i.e. the share of RES-E promotion of the electricity bill). Their study finds that the additional cost for the consumer increased annually by 23 percent during the period considered.

However, some properties of RES-E generation could also potentially counteract the upward-price effect associated with FITs. The marginal cost of most renewable electricity generation is zero or close to zero. Once a plant has been put in place, the generator produces electricity at almost no extra cost. As utilities are mandated to take off this electricity and pay the generator a fixed price, this electricity is practically free (in the sense of already paid for). The marginal technology determining the wholesale price therefore depends on the level of "residual demand," defined as the electricity demanded minus the feed-in of electricity from RES-E. If the residual demand is low, the marginal power plant is less expensive than if the residual demand is high. Dependent on the price elasticity of power demand, RES-E generation pushes more expensive marginal plants (e.g., natural gas, petroleum, etc.) out of the market, which not only displaces the generation costs of these generators but also reduces inframarginal rents earned by all non-marginal sellers in the spot market. High feed-in of RES-E thus shifts the supply curve for electricity to the right, resulting in lower wholesale electricity prices. This is what Ragawitz, Sensfuß, and Barbose (2008) term the "merit-order effect."

In particular, there could be a substantial "time-of-day" effect that is related to the merit order. The merit-order effect could be particularly strong during peak time if RES-E was able to replace extremely expensive "super-peaker" plants, whereas it could be almost negligible during times of low demand. In extreme cases, the merit-order-related price savings across the entire electricity market could outweigh the costs of paying renewable generators above-market rates, depending on the magnitude of the tariff and the price reduction.

Some empirical analysis has confirmed that more RES-E supply can decrease spot-market prices in practice. Weigt (2009) finds that wind generation had a downward impact on both spot-market prices and generation costs in Germany for the period of 2006 to 2008. During the observation period, the study estimates a total savings of €4.1 billion due to wind power fed into the grid. Traber and Kemfort (2011), using a mixed complementary program computational model, also find that higher wind supply reduces German market prices by more than 5 percent. Their model estimates that the reduction in the spot-market price for electricity is 0.37 Eurocents per kWh.

Similar results have also been found in Spain. Gelabert, Labandeira, and Linares (2011), using a multivariate regression model of hourly electricity prices for 2005 to 2009, find that a marginal increase of 1 GWh of electricity from renewable sources is associated with a reduction of almost 4 percent (€2 per MWh) in wholesale electricity prices. Likewise, Jonsson, Pinson, and Madsen (2010) use a non-parametric least squares model regressing hourly area spot-prices on wind power forecasts for January 2006 to October 2007 to show that positive wind forecasts result in lower spot-market prices for the DK-1 price area of the Nordpool electricity area.

Comparing potential cost savings from higher RES-E feed-in to direct costs of the FIT, Bode (2006) shows that power costs might decrease due to FIT schemes such as the German EEG under certain conditions. Similarly, Rathmann (2007) shows that the support for renewable energy created by the German feed-in tariff can result in lower electricity prices. Ragawitz, Sensfuß, and Barbose (2008), offering a detailed analysis of the price effects of renewable electricity generation on German spot-market prices between 2001 and 2006, find a considerable reduction in wholesale electricity prices associated with higher levels of RES-E fed into the grid. Furthermore, they find that in 2006 cost savings due to RES-E feed-in actually outweighed the direct costs of the FIT. Similarly, De Miera, del Rio Gonzalez, and Vizcaino

(2008), using hourly historical data, find that the reduction of the wholesale price of electricity as a result of more RES-E generation being fed into the grid is greater than the increase in consumer prices for electricity that arise from the FIT scheme.

In contrast, OPTRES (2007) projects that the direct effect of the FIT will outweigh the indirect reduction of wholesale prices. Although it estimates that the total amount of avoided fossil fuels will reduce costs for the EU27 by €23 billion from the year 2020 onward, the study expects the costs of RES-E generation to be higher.

The merit-order effect has further implications for the long-term effects of supporting RES-E. FIT schemes do not run infinitely; the contract duration typically lies somewhere between 12 and 20 years. The scheme is supposed to enable developers to recover their capital investment over the contract period. Once the contract expires, the price of electricity from those generators is driven by companies' (actual) variable costs. Therefore, the long-term price effects of FITs may be much more beneficial to consumers if they result in a lot of renewable generation capacity installed that will still be around after the FIT contract period has ended.

This long-term effect also applies to hydro and nuclear facilities. Similar to RES-E technologies such as wind and solar PV, both technologies have extremely low operating costs compared to the high up-front capital investments required to build the plants. Once these plants have recovered the initial capital investments, they are able to generate electricity relatively cheaply. Moreover, a larger share of electricity generation from hydro and nuclear sources decreases wholesale prices as it replaces generation from fossil fuels with higher marginal costs.

Table 1. EU Member States Included in the Dataset

Austria	Finland
Belgium	France
Czech Republic	Germany
Denmark	Greece
Estonia	Hungary
Ireland	Slovak Republic
Italy	Slovenia
Netherlands	Spain
Poland	Sweden
Portugal	United Kingdom

III. DATA

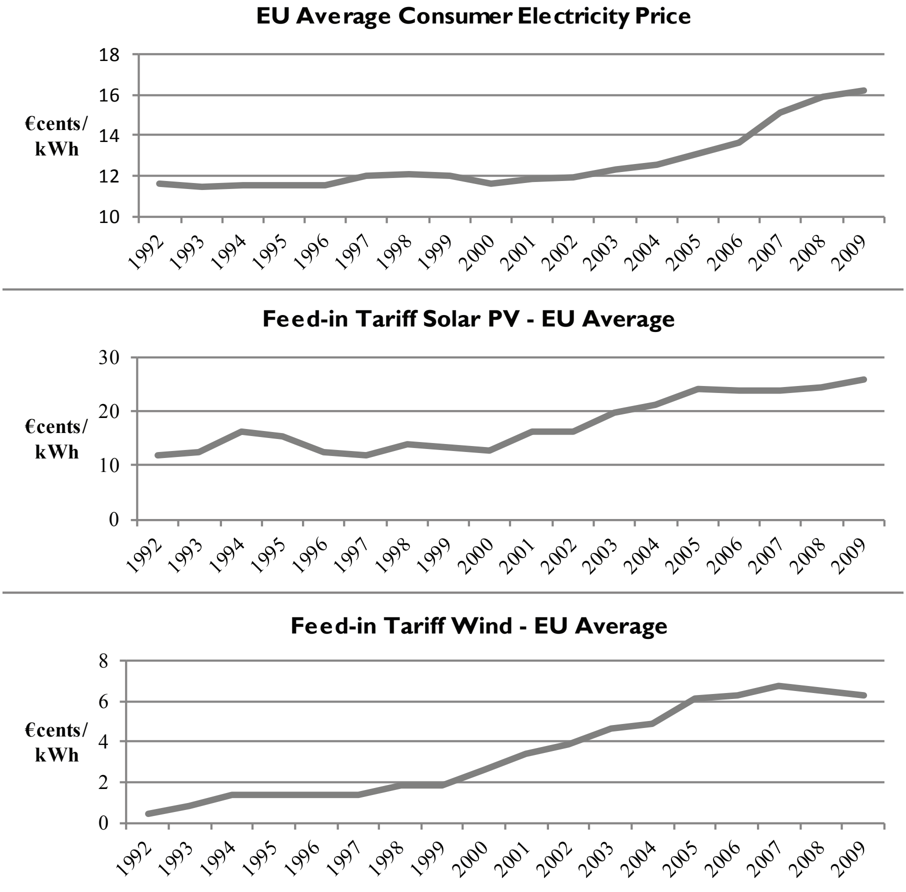
The dataset used in this study covers 20 European Union member states for the period of 1992 to 2009, and consists of data related to and representing the factors influencing electricity prices identified above.

Dependent Variable Selection

This study focuses on the effects of FIT policies on household consumer electricity prices for conceptual and technical reasons. Firstly, adverse price impacts at the household level are likely to have the most direct socioeconomic consequences as they directly affect welfare and inflation levels. As all EU member states are democracies, adverse price effects may potentially trigger backlash against FIT policies. Retail rates thus constitute the most politically relevant pricing unit for study. Although utility companies could mitigate the effect of FIT policies on retail consumers by cross-subsidizing rates for small-scale consumers at the expense of commercial consumers, such cross-subsidization is difficult to capture and typically works the opposite way in developed countries, with residential customers subsidizing businesses (IEA 2005).

Secondly, as electricity covered by the FIT is, in most cases, not actually traded on the spot market (because the payment amount is fixed), analyzing effects on spot prices would stop short of the full impact of FIT policies on electricity prices. Therefore, the dependent variable for this analysis is average yearly retail prices for electricity in €cents/kWh, for household consumers with an annual consumption of 3,500 kWh, including all taxes and levies. The data are obtained from EUROSTAT (2012) for EU member states for the time period 1992 to 2009.

Figure 2. Average Electricity Prices and FITs



Main Policy Variables

The main independent variables of interest are the tariff amounts for FIT in €cents/kWh in EU member states. I obtain data on tariff amounts for onshore wind and solar PV from Groba, Indvik, and Jenner (2011). The dataset reports the mean value of the PV tariff across all size, location, and ownership categories, but fails to capture the complete extent of heterogeneity in FIT policies across countries. This shortcoming may result in a bias of the error term; however, as the unit of analysis is the country level, limitations of this kind have to be accepted to allow for feasibility.

Figure 2 shows that the average FIT has increased throughout the sample period in parallel with the average retail electricity price.

In an attempt to cover more of the existing policy heterogeneity, I also multiplied the tariff amount by the number of years generators receive the FIT under a country's respective policy regime and used the result as an alternative specification of the main policy variable. Data on contract duration was again obtained from Groba, Indvik, and Jenner (2011). As the exact amount of electricity generation under the FIT is not constant over the years due to changes in weather conditions and future payments were not discounted to the present, this measure fails to capture the exact annual payments made under the program, but nonetheless adds a critical dimension to the measure of overall payments provided by the respective policies.

Fossil Fuel Input Costs

In order to approximate the variable costs for generating electricity in the economy, I include the costs of the fossil fuel inputs as the most important (variable) cost factor of generating electricity. To approximate these costs, I multiply the shares of electricity generation from coal, natural gas, and petroleum with those inputs' respective import prices, as most European countries import those fossil fuels. Both import prices and shares were obtained from the IEA's Electricity Information Statistics database. As IEA did not report import prices for each of the 20 member states and/or all 16 years in the panel, some values had to be imputed based on strong assumptions about member states' characteristics in terms of import costs.[2] The upward trend in household

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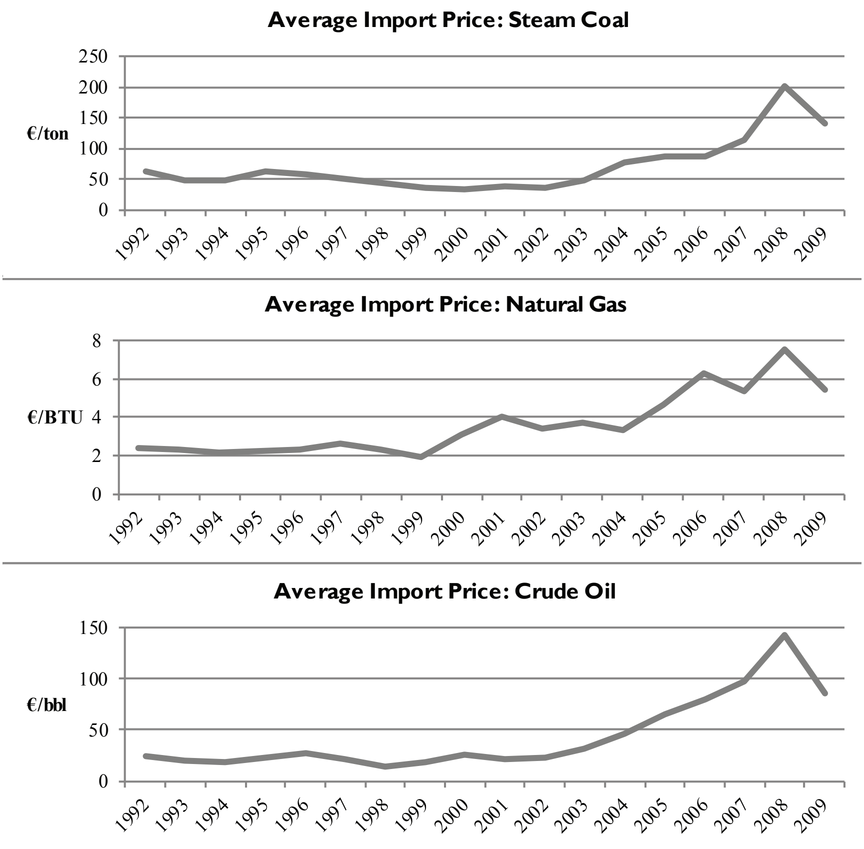
[2] As coal and petroleum are traded on a global market, differences in import prices are largely driven by transportation costs, such as availability of shipping and rail capacity. Countries with similar geographic characteristics can therefore be assumed to have relatively similar import costs. Missing values for import prices were thus imputed based on the values reported for neighboring states with similar geographic characteristics. Analogous reasoning was applied for imputing natural gas import prices, which critically depend on availability of pipeline capacity.

For countries that did not report import prices for all panel years, I calculate an average "spread" multiplier between the existing observations and the European average as reported by IEA. Missing variables were imputed by multiplying this "transportation" multiplier with the European average.

These methods assume that the transport costs are driven by geographic factors and do not change over time. In cases where they do, this

Figure 3. Fossil Fuel Import Costs over Time



electricity prices is also matched by a continuous increase in fossil fuel import prices until 2008 (Figure 3), when the latter dropped sharply due to reduced demand in the wake of the global financial crisis.

Additional Explanatory Variables

In order to complete the energy mix, the shares of electricity generated from hydro and nuclear power are also included. The variable costs of these technologies are very low, so shares were not multiplied by any input prices although nuclear power relies on materials such as uranium or plutonium for nuclear fission. The shares of electricity generated from hydro and nuclear power are also obtained from the EIA electricity information statistics database.

I also include a capacity factor variable to capture the relative capital-intensity of electricity generation, using data from the IEA electricity information database. The capacity factor is the only variable in the model that attempts to capture the cross-country differences

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may bias the error term. This is particularly problematic for countries that only reported values toward the end of the panel, as the methodology may not account for structural changes (such as rail or pipeline capacity) between the beginning and the end of the panel.

in the structural costs of generation, although it cannot capture the full capital costs embedded in retail rates.

I further include binary indicator variables for whether end-user prices were regulated by a government agency and for whether countries have enacted a requirement on utilities to generate a minimum share of the electricity from renewable sources. The information to construct these indicators is obtained from the country profiles of the IEA 2011 Electricity Information and ECME 2010 as well as from RES-Financing (2011) and OPTRES (2007), respectively.

IV. EMPIRICAL METHODS & MODEL SPECIFICATION

In order to capture some of the underlying capital costs of generating and supplying electricity in structurally different markets, controlling for country-level fixed effects (FE) is necessary. For example, a small country like the Netherlands, with relatively moderate weather and high population density, will have relatively low structural costs compared to large countries with extremely cold winters or extremely hot summers and low population density. These factors are unlikely to show much year-to-year variation.

While there is a relatively clear indication of a country fixed effect, accounting for time-specific changes in capital costs is more challenging. Although certain yearly effects related to input fuel prices are felt the same way across all countries, notably the costs for fossil-fuel inputs such as coal and petroleum, most time effects related to electricity prices occur within individual countries. These effects are largely related to a country's market structure and political system, for example in the competitiveness of wholesale or retail markets. Changes in these factors do not occur at the same time across countries. Whereas some countries like the UK saw multiple restructurings during the panel period, other markets have seen few changes in competitiveness (Cooke 2011). Omitting within-country structural changes in the costs of generating and supplying electricity (or any variable that can capture it) is likely to introduce autocorrelation into the error term of the model, as countries that have low embedded capital costs in year t are very likely to also have low embedded capital costs in year $t-1$. The Wooldridge test for first-order autocorrelation thus strongly rejected the null hypothesis of no first-order autocorrelation when omitting the embedded capital costs.

In order to capture the country- and year-specific underlying capital costs, eliminate the serial correlation, and address the clear upward trend in the dependent variable, I estimate a linear dynamic panel-data model that includes a lag of the dependent variable as a covariate as well as unobserved panel-level fixed effects. Bond (2002) emphasizes that even when coefficients on lagged dependent variables are not of direct interest, allowing for dynamics in the underlying process may be "crucial for recovering consistent estimates of other parameters." In my model, the previous year's retail price is understood to capture the unobserved variation in the embedded capital costs due to the strong relationship between retail prices and capital costs. As underlying capital costs are likely to only change slowly over time, the prior year's retail price offers a good approximation of the changes in embedded capital costs. All models soundly reject the null hypothesis that all coefficients except the time trend (lagged DV) are zero, tested through the chi-squared test reported by Arellano and Bond, and show that the rest of the model has explanatory power that goes considerably beyond the time trend.

Guided by this framework, I estimate the following base model:

$$RETAIL\ PRICE_{it} = \beta_1 RETAIL\ PRICE_{i,t-1} + \beta_2 FIT(wind)_{it} + \beta_3 FIT(solar)_{it} + \beta_4 Coal\ Input\ Cost_{it} + \beta_5 Natural\ Gas\ Input\ Cost_{it} + \beta_6 Petroleum\ Input\ Cost_{it} + \beta_7 Hydro_{share} + \beta_8 Hydro_{share} + \beta_9 Capacity\ factor + \beta_{10} RPS + \beta_{11} Regulator + \nu_i + \varepsilon_{it} \tag{1}$$

As the panel level effect ν_i is the same across time periods, it is by construction correlated with the lagged dependent variable because the dependent variable in year t–1 is also affected by ν_i , making the standard estimators inconsistent. In order to address this problem, I use the Arellano and Bond (1991) generalized method-of-moments (GMM) estimator, which was first proposed by Holtz-Eakin, Newey, and Rosen (1988). This method uses estimators constructed by first differencing to remove the panel-level effects and further lags of the dependent variable to create instruments of the lagged dependent variables and remove the autocorrelation. When the idiosyncratic errors εit are independently and identically distributed, the first differenced errors are first-order serially correlated in the Arellano-Bond specification.[3] However, assuming that ε_{it} is serially uncorrelated, the predetermined initial conditions imply that the lagged level $y_{i,t-2}$ will be uncorrelated with $\Delta\varepsilon_{it}$ and thus available as an instrument for the first differenced equation (Bond 2008). Serial correlation at order 1 thus does not invalidate the moment conditions used by the Arellano-Bond estimator, because only lags of two time periods and further are used as instruments. Apart from the lagged dependent variable, the first difference of all exogenous variables is used as standard instruments.

All models were tested for second-order autocorrelation with the Arellano-Bond post-estimation test for zero autocorrelation. The test is applied to the differenced residuals, and the null hypothesis is that there is no autocorrelation. As expected, the test for autocorrelation at order 1 in the first differences rejects the null hypothesis, but the test fails to reject

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[3] As $\Delta\varepsilon_{it} = \varepsilon_{it} - \varepsilon_{i,t-1}$ and $\Delta\varepsilon_{i,t-1} = \varepsilon_{i,t-1} - \varepsilon_{i,t-2}$ both terms contain $\varepsilon_{i,t-1}$. Therefore the test for AR(1) is expected to be failed, and the test for AR(2) is decisive.

it at the second order, presenting no significant evidence of serial correlation in the first-differenced errors at order two or higher. The tests for autocorrelation thus present no evidence for model misspecification.

The Arellano-Bond method constructs the GMM estimator using as many lags of ε_{it} as are available in the panel. For long panels (panels with a large amount of time periods *t*) this potentially leads to over-identification. Over-identification in itself is generally desirable; however, there is potential danger of correlation between the over-identifying instruments and the residuals, which would invalidate the central assumption of the Arellano-Bond estimation that the instruments as a group need to be exogenous. In order to maintain instrument exogeneity, the number of lags used as instruments is restricted to 10. This represents the maximum number of lags that still allow the basic model specification to pass the Sargan test, which tests whether the residuals are uncorrelated with the set of constructed instruments. Subsequently, lags from two time periods back to 11 time periods are used to create the GMM type instruments described by Arellano and Bond (1991), in order to ensure instrument exogeneity.

The results are displayed in Table 2 next to the results of standard FE regression. The results for the Arellano-Bond and OLS estimations are relatively closely matched, though the coefficient estimate for the feed-in tariff for solar PV is significant under OLS but not under the Arellano-Bond estimate. This similarity can be explained by the fact that the Arellano-Bond estimator was designed for panels with many observations and only few time periods. However, the panel used in this analysis, although consisting of more *n* than *t*, was relatively evenly matched, covering 20 countries over 16 years. According to Rodman (2006), the correlation of the time trend with the error term will be less significant in panels with many time periods, as a shock to the country fixed effect that could affect the error term will decline over time.

> “The empirical analysis indicates there are clear adverse price effects associated with supporting electricity generation from wind through feed-in tariff schemes, although they are relatively small in magnitude.”

V. EMPIRICAL RESULTS

Table 2 displays the empirical results of several alternative specifications of the main regression outlined in Equation 1.

Main Policy Variables

The empirical analysis indicates that there are clear adverse price effects associated with supporting electricity generation from wind through feed-in tariff schemes, although they are relatively small in magnitude. The results from model 1 show that an extra cent FIT for wind raises the retail electricity prices for residential consumers by approximately 0.06 cents. This corresponds to roughly 0.5

Table 2. Empirical Results

	Arellano-Bond Estimator				OLS with country FE			
	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
VARIABLES	l	l	l	l	l	l	l	l
lag-price	0.754***	0.742***	0.741***	0.729***	0.877***	0.874***	0.880***	0.874***
	(0.060)	(0.061)	(0.059)	(0.060)	(0.034)	(0.034)	(0.034)	(0.034)
tariff_wind	0.063**		-0.023		0.059**		-0.033	
	(0.031)		(0.053)		(0.024)		(0.039)	
tariff_pv	-0.006		0.002		-0.008**		-0.003	
	(0.006)		(0.010)		(0.004)		(0.008)	
totalpay_wind		0.005**		-0.003		0.004***		-0.003
		(0.002)		(0.005)		(0.002)		(0.004)
totalpay_pv		-0.000		0.000		-0.000**		-0.000
		(0.000)		(0.001)		(0.000)		(0.000)
tariff*regulator_wind			0.101**				0.112***	
			(0.051)				(0.037)	
tariff*regulator_pv			-0.010				-0.006	
			(0.008)				(0.006)	
totalpay*regulator_wind				0.008*				0.009**
				(0.005)				(0.003)
totalpay*regulator_pv				-0.001				-0.000
				(0.000)				(0.000)
coal_input_cost	0.011	0.011	0.014*	0.014**	0.004	0.004	0.005	0.005
	(0.007)	(0.007)	(0.007)	(0.007)	(0.006)	(0.006)	(0.006)	(0.006)
petro_input_cost	0.002	0.008	-0.019	-0.019	0.097*	0.102**	0.098**	0.105**
	(0.073)	(0.073)	(0.073)	(0.072)	(0.050)	(0.050)	(0.049)	(0.049)
gas_input_cost	0.349**	0.342**	0.417***	0.403***	0.162	0.150	0.197*	0.185*
	(0.148)	(0.147)	(0.145)	(0.145)	(0.106)	(0.106)	(0.106)	(0.107)
share_hydro	-2.623*	-2.604*	-2.709*	-2.780*	-1.875*	-1.811*	-1.627	-1.424
	(1.549)	(1.540)	(1.544)	(1.536)	(1.090)	(1.083)	(1.082)	(1.091)
share_nuclear	-7.313**	-7.160**	-6.641*	-6.617*	-3.975	-3.861	-3.031	-2.901
	(3.658)	(3.636)	(3.682)	(3.654)	(2.459)	(2.444)	(2.506)	(2.491)
capacityfactor	-0.400	-0.423*	-0.392	-0.386	-0.316	-0.282	-0.279	-0.244
	(0.246)	(0.246)	(0.247)	(0.248)	(0.195)	(0.194)	(0.193)	(0.193)
rps	-0.063	-0.022	-0.198	-0.133	0.024	0.044	-0.173	-0.168
	(0.309)	(0.308)	(0.314)	(0.312)	(0.230)	(0.231)	(0.247)	(0.248)
regulator	-0.697**	-0.694**	-0.974**	-1.016**	-0.368*	-0.379*	-0.841***	-0.893***
	(0.284)	(0.283)	(0.428)	(0.417)	(0.199)	(0.199)	(0.321)	(0.317)
Observations	287	287	287	287	320	320	320	320
Number of code	20	20	20	20	20	20	20	20
R-squared					0.880	0.881	0.884	0.883

Standard errors in parentheses.

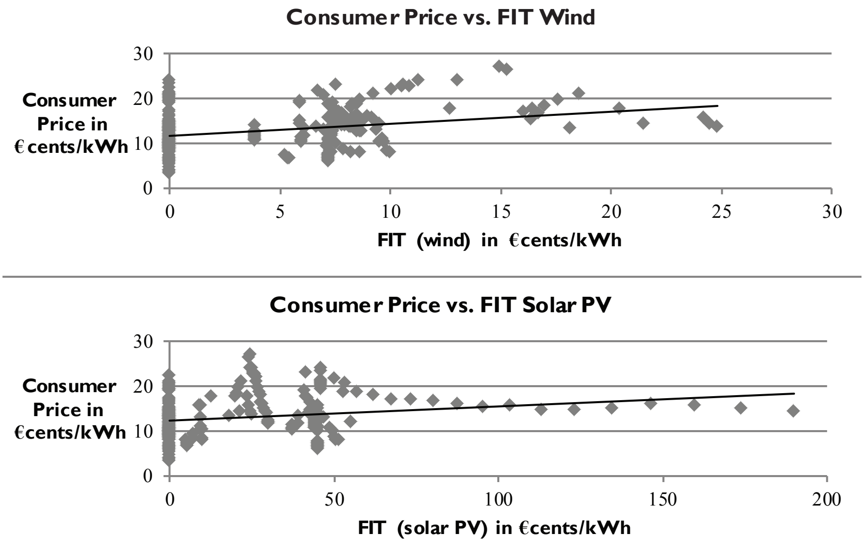
*** p<0.01, ** p<0.05, * p<0.10

percent of the average retail price for electricity throughout the panel. Given that the mean FIT tariff for wind is 3.6 cents, this implies that the presence of an FIT that pays exactly the mean tariff amount results in an electricity price that is 0.22 cents per kWh higher than in the absence of the FIT, approximately 2 percent of the average retail rate. For countries with successful FIT programs, such as Germany, that paid an average tariff of approximately 8 cents over the period of the panel, this corresponds to an increase in electricity prices of 0.48 cents per kWh, approximately 3 percent of the average retail price in Germany.

The coefficient of FIT for wind is highly statistically significant throughout all models and sensitivity tests, and the magnitude of the coefficient remains relatively unchanged. The coefficient decreases considerably when using the total payment amount over the contract duration, to approximately 0.04 percent of average retail prices in the panel. Increasing this value by 1 unit (either by increasing the tariff or by extending the contract period) increases retail electricity prices by 0.004 cents per kWh.

Interestingly, the coefficient for the feed-in tariff on solar PV is negative throughout all model specifications, although the magnitude of the coefficient is so small that it does not appear economically relevant. Statistical significance decreases when estimating the Arellano-Bond estimator, whereas the sign and magnitude of the effect remain relatively unchanged. However, the comparatively small magnitude of the effect may result from the fact that, currently, only a relatively small share of electricity is generated from solar PV, and many European countries have only put FIT policies in place relatively

Figure 4. Scatter Consumer Price vs. Tariff Amounts



recently. The mean of electricity generated from solar PV is 0.03 percent of total generation, although in market leaders Germany and Spain it is more than 0.17 percent. In contrast, the mean for wind generation is considerably higher at approximately 1.4 percent, with leaders Denmark and Spain at 10.3 and 3.9 percent, respectively. This result may change once countries develop greater solar generation capacity.

The negative coefficient may also be driven by the fact that all observations with tariff amounts greater than 60 cents are all from one country (Germany), which decreased its support for solar PV generation throughout the panel. The scatter graph provided in Figure 4 further illuminates this relationship. Nonetheless, my estimations indicate that, to date, supporting electricity generation from solar PV has had no effect on electricity retail prices.

Other Policy Variables of Interest

Higher shares of hydro and nuclear power in the electricity generation mix are associated with lower retail electricity prices; the coefficients for shares of electricity generated from both hydro and nuclear power were extremely large and negative across all models, with high to moderate levels of statistical significance.

> "The empirical results ... stand in stark contrast to the economic concerns regularly voiced by the opponents of such policies."

Retail price regulation is also associated with lower retail electricity prices. The coefficient on end-user price regulation is statistically significant and negative throughout all models. If end user prices are regulated by a government agency, they are approximately 0.7 cents per kWh lower than if they are not regulated.

The regulator variable is also of particular importance to the FIT debate. Models 3 and 4 show that in countries with retail price regulation, the effect of the FIT is highly statistically significant. In contrast, the effect of the FIT becomes insignificant for countries that do not regulate retail rates.

VI. DISCUSSION

The empirical results suggest that European feed-in tariff programs for electricity generated from wind and solar PV have had relatively little effect on retail electricity prices. This finding stands in stark contrast to the economic concerns regularly voiced by the opponents of such policies. In combination with the well-established success of FIT programs in spurring installation of RES-E generation capacity in countries such as Denmark, Germany, and Spain, the results presented in this paper support the view that well-designed FIT programs are not only the most successful, but also an economically viable policy option for supporting RES-E.

The results further suggest that there is a distinct difference in the price-effect of FIT legislations depending on the technology supported. The diverging findings for wind and solar PV are of great interest, as they point to the existence of the so-called "merit-order effect" as described by Ragawitz, Sensfuß, and Barbose (2008). While wind generates electricity mostly during off-peak periods at night, solar PV generates electricity during times when electricity demand is actually high, such as during clear, cold winter days and hot summer days. Therefore, solar PV can replace costly natural gas and petroleum plants, whereas wind electricity only replaces electricity generated from base-load coal, hydro, and nuclear plants with comparably low marginal costs, if these plants can even be shut down. Positive price-effects from replacing more costly technologies are therefore comparatively smaller for electricity generated from wind. However, the results for solar PV need to be treated with particular care given the small share of electricity produced by this technology.

The fact that the price increases associated with FITs for wind is only statistically significant when retail prices are still regulated suggests that regulators accommodate for increased costs incurred by utility companies by allowing them to charge higher retail rates. This result is particularly interesting in the light of recent developments in Spain, where the energy regulator CNE has failed to raise consumer prices appropriately for utilities to recover their costs. *The Economist* (2011) reports the resulting annual "electricity-tariff deficit" (the differential between utility companies' costs and revenue) has risen dramatically to €5.6 billion ($8.3 billion). As a result, FIT payments have been cut retrospectively to alleviate utilities' burdens, although the main cause for the "deficit" is likely rising raw-material prices. However, given that there is no significant effect of the FIT for wind if retail markets are liberalized (in fact, the coefficients throughout all models are negative), the empirical results indicate that efficiency gains from competition prevent retail rates to rise in the presence of FITs. This finding points toward a positive interaction between market liberalization at the retail level and RES-E support through FIT policies, which warrants some more focused exploration in the future.

> "... well-designed FIT programs are not only the most successful, but also an economically viable policy option for supporting RES-E."

The finding that the coefficient on retail regulation is negative stands in contrast to the literature on retail price deregulation, which suggests that market liberalization should lower prices rather than increase them. However, in the absence of functioning retail markets, utilities may be able to charge higher prices and thus extract rents from consumers. This is particularly true if retail electricity prices have previously been subsidized. Therefore, retail price regulation might shield consumers from higher prices.

> “Even though rising retail rates are a serious concern for social welfare, this study suggests that in the last two decades such effects have largely been driven by factors other than FITs.”

The result that both hydro and nuclear power are associated with lower retail electricity prices across all model estimations also wields considerable explanatory power in explaining the price effects of FIT policies. With respect to its cost profile, electricity generation from wind and solar is very similar to hydro and nuclear. Most European nuclear and hydro plants are relatively old and thus have already paid off their enormous capital costs. Seeing that larger shares of hydro and nuclear generation are associated with a large decrease in retail rates in the long term, the same may hold true for wind and solar, once the initial investments necessary to expand capacity to significant levels are paid off. Given that the FIT programs were not established until the early 1990s and most countries have not even completed the first cycle of FIT contracts, it is unlikely that renewable capacity installed under any FIT regime has already recovered the initial capital investment. In this context, feed-in tariff schemes could play an instrumental part in getting this capacity installed and allowing for such low-cost generation in the future.

VII. CONCLUSION

Overall, the relatively modest price increases associated with FIT policies (for wind) found by this analysis should not overly concern European policy makers. Even though rising retail rates are a serious concern for social welfare, this study suggests that in the last two decades such effects have largely been driven by factors other than FITs. In light of the price-decreasing effects of larger shares of hydro and nuclear power in a country’s energy mix—and both wind’s and solar PV’s extremely similar cost profile—substantial investment into these technologies could actually result in lower electricity prices in the long run, as wind and solar generators replace more expensive natural gas and/or petroleum generation plants.

Considering the successful track record of FITs in increasing RES-E capacity in combination with these relatively low costs, feed-in tariff policies continue to be an extremely attractive policy tool for supporting RES-E. Nonetheless, policy is not an absolute and even successful policies need to be monitored and evaluated constantly. In particular, tariff rates need to be adjusted as technologies mature to accurately reflect development costs and ensure that the security guaranteed to investors under FIT schemes does not turn into excessive profits paid for by the consumer.

VIII. REFERENCES

Alagappan, L., R. Orans and C. Woo. 2011. What drives renewable energy development. *Energy Policy* 39: 5099-5104.

Arellano, M. and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies* 58, no. 2: 277-297.

BMU. 2011. Environment Minister Röttgen: Solar power support must be adjusted to market developments. Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety, January 20. http://www.bmu.de/english/current_press_releases/pm/46964.php.

Bode, S. 2006. On the impact of renewable energy support schemes on power prices. HWWI Research Paper. Hamburg, Germany: Hamburgisches Welt-Wirtschafts Institut.

Bond, S. 2002. Dynamic panel data models: A guide to micro data methods and practice. *CEMMAP* Working Paper. London, UK: Institute for Fiscal Studies.

Butler, L. and K. Neuhoff. 2008. Comparison of feed-in tariff, quota and auction mechanism to support wind power development. *Renewable Energy* 33: 1856-1867.

Cooke, D. 2011. Empowering customer choice in electricity markets. IEA Information Paper. Paris, France: International Energy Association.

De Miera, G., P. del Rio Gonzalez, and I. Vizcaino. 2008. Analyzing the impact of renewable electricity support schemes on power prices: The case of wind electricity in Spain. *Energy Policy* 36: 3345-3359.

Del Rio, P. and M. Gual. 2007. An integrated assessment of the feed-in tariff system in Spain. *Energy Policy* 35: 994–1012.

Drukker, D. 2008. Econometric analysis of dynamic panel-data models using Stata. Stata Corp Presentation at the North American Stata Users Group Meeting, July 24 – 25, in College Station, TX.

EC. 2008. The support of electricity from renewable energy sources. Accompanying document to the Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. Brussels, Belgium: Commission of the European Communities.

EC Roadmap. 2008. Renewable Energy Road Map Renewable energies in the 21st Century: Building a more Sustainable Future. Communication from the Commission to the Council and the European Parliament. Brussels, Belgium: Commission of the European Communities.

ECME Consortium. 2010. The Functioning of Retail Consumer Markets for Consumers in the European Union. Brussels, Belgium: Report for the Directorate-General for Health and Consumers.

The Economist. 2011. Renewable energy: Sunburned, July 26. http://www.economist.com/node/21524449.

EEG. 2009. Green-X. Deriving optimal promotion strategies for increasing the share of RES-E in a dynamic European electricity market. Vienna: Energy Economics Group of the Vienna University of Technology.

Eurostat. 2011. *Statistics Database*. Luxembourg: European Commission.

Frondel, M. et al. 2008. Economic impacts from the promotion of renewable energy technologies: The German Experience. *Energy Policy* 38: 4048-4056.

Fox-Penner, P. 1997. Electric utility restructuring—a guide to the competitive era. Vienna, VA: Public Utilities Reports Inc.

Gelabert, L., X. Labandeira and P. Lineares. 2011. Renewable energy and electricity prices in Spain. *Economics for Energy Working Paper*, Vigo, Spain: Energy for Economics.

Groba, F., J. Indivik, and S. Jenner. 2011. Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries. DIW Discussion Papers. Berlin, Germany: German Institute for Economic Research.

Helm, D. and A. Powell. 1992. Pool prices, contracts and regulation in the British electricity supply industry. *Fiscal Studies* 13, no. 1: 89-105.

Holtz-Eakin, D., W. Newey, and H. Rosen. 1988. Estimating vector autoregressions with panel data. *Econometrica* 56, no. 6: 1371-1395.

International Energy Agency. 2011. *Electricity Information Database*. Paris, France: Organization for Economic Cooperation and Development (OECD).

International Energy Agency. 2005. Russian electricity reform—emerging challenges and opportunities. Paris, France: OECD.

Jamasb, T. and M. Pollitt. 2005. Electricity market reform in the European Union: Review of progress toward liberalization & integration. *The Energy Journal* 26, no. I: 11-42.

Jonsson, T., P. Pinson and H. Madson. 2010. On the market impact of wind energy forecasts. *Energy Economics* 32: 313-320.

Lesser, J. A. and X. Su. 2008. Design of an economically efficient feed-in tariff structure for renewable energy development. *Energy Policy* 36, no. 3: 981-990.

Lipp, J. 2007. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy Policy* 35, no. 11: 5481-5495.

Mallet, Victor. 2010. Spain's solar power subsidy cuts attacked. *Financial Times*, December 22, http://www.ft.com/intl/cms/s/0/fdedc4d2-0dfb-11e0-86e9-00144feabdc0.html#axzz1qEmCx5Jm.

Newbery, D. 2002. Regulating unbundled network utilities. *The Economic and Social Review* 33, no. 1: 23-41.

Newberry, D. 1999. *Privatization, restructuring and regulation of network utilities–The Walras-Pareto lectures*. Cambridge, MA: MIT Press.

OPT RES. 2007. Assessment and optimization of renewable energy support schemes in the European electricity market. Report by order of the European Commission, DG Energy and Transport. Brussels, Belgium: European Commission.

Rathmann, M. 2007. Do support systems for RES-E reduce EU-ETS-driven electricity prices? *Energy Policy* 35: 342–349.

RES-Financing. 2011. Financing renewable energy in the European market. Report by order of the European Commission, DG Energy. Brussels, Belgium: European Commission.

REN21. 2010. Renewables global status report. 2010 update, technical report, Renewable Energy Policy Network for the 21st Century. Paris, France.

RES-Legal. 2011. Legal sources on renewable energy. Berlin: German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

Rodman, D. 2006. How to do xtabond2: An introduction to "difference" and "system" GMM in Stata. DGDev Working Paper. Washington, DC: Center for Global Development.

Sensfuß, F., M. Ragawitz, and M. Genoese. 2008. The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany." Energy Policy 36: 3086– 3094.

Stata Corp. 2007. Longditudinal/panel data, *Stata statistical Software: Release 10*. College Station, TX: Stata Corp LP.

Stoft, S. 2002. *Power systems economics—designing markets for electricity*. New York, NY: The Institute of Electrical and Electronics Engineers.

Traber, T. and C. Kemfort. 2009. Impacts of the German support for renewable energy on electricity prices, emissions, and firms. *The Energy Journal* 30, no. 3: 155-177.

Traber, T. and C. Kemfort. 2011. Gone with the wind?—Electricity market prices and incentives to invest in thermal power plants under increasing wind energy supply. *Energy Economics* 33: 249-256.

Weigt, H. 2009. Germany's wind energy: The potential for fossil capacity replacement and cost saving. *Applied Energy* 86: 1857–1863.

Wooldridge, J. 2009. *Introductory econometrics: A modern approach.* Mason, OH: Cengage Learning.