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The Determinants of Entry
in The Electricity Generation
Sector in OECD Countries:
A Focus on Renewable
Energy

**David Benatia,
Tomasz Koźluk**

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ENVIRONMENT DIRECTORATE

THE DETERMINANTS OF ENTRY IN THE ELECTRICITY GENERATION SECTOR IN OECD COUNTRIES: A FOCUS ON RENEWABLE ENERGY - ENVIRONMENT WORKING PAPER No. 111**By David Benatia (1) and Tomasz Koźluk (2)**

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ABSTRACT

Ease of entry is crucial to well-functioning electricity markets. This paper investigates the patterns of entry in the generation segment of the electricity industry of OECD countries and seeks to provide an understanding of their key determinants. It aims to derive implications for the design of policies aimed at spurring competition under significant renewable policy objectives. The analysis focuses on investments in renewable-based electricity generation in all OECD countries over the period 1990-2007. Hypotheses drawn from the literature are tested empirically with using a panel data set based on UDI's World Electric Power Plant Database. Findings suggest that the likelihood and the volume of entry in renewable-based power generation technologies are significantly affected by industry regulation, renewable support policies, local structural industry characteristics, such as concentration, sectoral expansion and the share of renewable-based capacity already present in the host country. Finally, micro-level factors such as the size of the (parent) firm, its experience with renewables, and whether it is a utility company, are found to significantly affect firm-level investment and entry decisions.

Keywords: Electricity generation, electricity market liberalisation, market structure, regulation, competition, market entry, renewable energy, energy policy.

JEL Classification: L94, L10, Q40

RÉSUMÉ

La facilité d'entrée sur les marchés de l'électricité est cruciale pour leur bon fonctionnement. Ce rapport étudie les schémas d'entrée dans le segment « production » du secteur de l'électricité dans les pays de l'OCDE, et s'efforce d'en élucider les principaux déterminants. Il vise à en tirer les conséquences pour la conception de politiques destinées à stimuler la concurrence en tenant compte d'objectifs ambitieux concernant les énergies renouvelables. L'analyse s'intéresse principalement aux investissements dans les moyens de production électrique renouvelables de tous les pays de l'OCDE sur la période 1990-2007. Des hypothèses tirées d'une revue de la littérature sont testées empiriquement en appliquant divers modèles économétriques à des jeux de données de panel provenant, pour l'essentiel, de la base de données World Electric Power Plant Database de l'Utility Data Institute (UDI). Les résultats obtenus permettent de conclure que de nombreux facteurs affectent la probabilité d'entrée sur le marché et le volume de ces entrées dans la production d'électricité renouvelable au niveau régional, notamment la réglementation du secteur, les politiques de soutien aux renouvelables, l'innovation, l'expansion sectorielle et la part de puissance installée reposant sur les renouvelables dans le pays concerné. Enfin, il apparaît que certains facteurs au niveau microéconomique, par exemple la taille de l'entreprise, son expérience dans le domaine des énergies renouvelables ou le fait qu'elle soit ou non une compagnie d'électricité, exercent une influence considérable sur les investissements au niveau des entreprises et les décisions d'entrée.

Mots-clés : Électricité, production d'électricité, libéralisation du marché de l'électricité, structure du marché, réglementation, concurrence, entrée sur le marché, énergies renouvelables, politique énergétique.

Classification JEL : L94, L10, Q40

NOTE FROM THE SECRETARIAT

The objective of the paper is to yield empirical insight on the determinants of entry patterns in electricity generation across OECD countries, focusing in particular on renewable energy. David Benatia is a Ph.D. candidate at the Economics Department of the University of Montreal. Tomasz Koźluk works at the Environment Directorate and Economics Department, OECD. The authors would like to thank Mauro Pisu, Nick Johnstone, Ivan Haščič, Miza Noor Muhamad Razali and Miguel Cárdenas Rodríguez for helpful comments and Barbara Aiello and Natasha Cline-Thomas for editorial support. Work on this paper was conducted under the overall responsibility of Shardul Agrawala, Head of the Environment and Economy Integration Division.

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EXECUTIVE SUMMARY

The electricity supply industry has evolved considerably over the past two decades. Many developed countries have introduced comprehensive electricity sector reform programmes aimed at liberalising and privatising their electricity industry. In addition, the implementation of economic instruments aimed at fostering renewable energy sources has widely contributed to shape today's markets for electricity generation.

However, several potential problems associated with market power in liberalised electricity industries have been recognised. Achieving a sufficient degree of competition within the generation segment of the electricity supply industry requires an adequate number of competing firms geographically spread over the transmission network in a way to limit the probability for local market power arising from transmission constraints. Therefore, facilitating entry of new firms into the industry is key to securing welfare-enhancing outcomes from electricity industry liberalisation reforms.

Four types of barriers may restrain entry into markets for power generation. *Structural barriers* include high economies of scale, large capital requirements, high upfront sunk costs and long lead times. *Regulatory barriers* may limit entry as they entail non-trivial supplementary costs, risks and delays to prospective entrants. Projects with very long time horizons like power plants are subject to significant *uncertainties about future prices*, market conditions, future costs, and the regulatory and policy frameworks. Finally, *strategic behaviour aimed at deterring new competition* can arise from excess capacity, vertical integration and locational advantages.

This report investigates the patterns of entry in the generation segment of the electricity industry in OECD countries, and seeks to provide an understanding of its key determinants. The purpose of this document is two-fold. Firstly it evaluates the important factors influencing the entry of new generation into the domestic market, for both new firms, with no presence so far, and incumbent firms, which already have a presence, albeit in a different generation technology. Secondly, it assesses the determinants of entry into the different generation technologies, in particular those based on renewable energy sources, to derive implications for the design of policies aimed at spurring competition in light of increasingly significant renewable energy objectives.

Several hypotheses drawn on a literature review are tested empirically with non-structural econometric models using a panel data set mostly based on UDI's World Electric Power Plant Database. The estimations focus on investments in renewable-based generation capacity in the electricity supply industry of all OECD countries over the period 1990-2007.

The analysis suggests that the likelihood and the volumes of entry in renewable-based power generation capacity at the domestic level exhibit the following features:

- Renewable support policies and industry regulation are estimated as key determinants of entry in the electricity generation sector.
- Feed-in tariffs (FIT) and renewable energy certificates (REC) are evaluated to have important entry-inducing effects, often larger than other policy support instruments.
- FIT are consistently found to have had greater impacts on entry and capacity investments than REC.

- As electricity supply is gradually liberalised, the pool of incumbents grows naturally. The consequent fall in the contribution rates of entrants to new capacity additions is reduced in the presence of FIT.
- Wind electricity generation, which generally is a developing technology with relatively low capital requirements, exhibits highest new entry rates and volumes, after controlling for other factors. More mature technologies, also often associated with high capital requirements, such as geothermal and hydro tend to have lower entry rates and capacity additions due to new entrants. Similarly, new entry and capacity additions in solar generation have been lower. .
- Entrants tend to invest in electricity generation projects of smaller capacity than incumbents.
- Incumbents are more likely to add capacity than entrants in already concentrated industries.

Firm-level investments in renewable-based generation capacity are found subject to similar macro-level determinants as those affecting country-level investments and entry. These include industry regulation, renewable support policies, innovation, sectoral expansion and the share of renewable-based capacity in the host country. At the micro-level, larger and better-established firms tend to undertake larger projects although utility companies appear to get involved in significantly smaller projects of fast-developing technologies, suggesting that they may be subject to inertia with regards to conventional power generation technologies. Finally, we find evidence in support of path-dependency and firm specialisation related to ‘green’ capacity investments. Firms with prior installations involving renewable technologies are generally associated with larger renewable projects although they tend to focus on a relatively narrow portfolio of generating technologies.

These findings underline the radical change from the classical electricity utility paradigm to a much less concentrated industry widely composed of highly specialised firms, where sound renewable energy support policies have a prominent role to play in achieving renewable policy objectives along with successful reforms of the electricity industry in OECD countries. Achieving a satisfactory degree of competition in the power generation markets in parallel of renewable energy goals will require taking advantage of the complementarities between environmental policies and industrial policies.

Further work would be necessary to extend the quantitative approach with a structural model of entry and market dynamics based on micro-level data, which would allow enhancing the quality of the analysis. Finally, the estimation is limited by the lack of comprehensive data on plant exit and the absence of actual time-series for generators’ ownership.

1. Introduction

The electricity supply industry has considerably evolved over the past two decades. Many developed countries have introduced comprehensive electricity sector reform programmes aimed at liberalising and privatising their electricity industry. In addition, the implementation of economic instruments aimed at fostering renewable energy sources, widely seen as means to mitigate polluting emissions of the electricity sector and improving energy security, has contributed to shape today's markets for electricity generation.

Electricity sectors evolved from vertically integrated geographic monopolies, either publicly owned or regulated as natural monopolies. While it is widely recognised that the distribution and transmission segments of the industry must remain regulated as monopolies for security and efficiency reasons, the introduction of competition in the generation and retail segments has been perceived as welfare-enhancing (Joskow, 2008). The primary goal of the liberalisation of electricity industries, through major structural reforms and the introduction of competitive wholesale and retail power markets, is to achieve improved economic efficiency in the entire sector while ensuring that an adequate share of the realised long-term social benefits is passed on to consumers through lower electricity prices (Kopsakangas-Savolainen and Svento, 2012; Joskow, 2008; IEA, 2005).

However, there are several potential problems associated with market power in liberalised electricity industries, as documented by the manipulation of power prices in California's wholesale markets (Borenstein, Bushnell and Wolak, 2002) and the other issues caused by market concentration in the United Kingdom, New Zealand, the PJM,¹ Texas, and Brazil, among others (Joskow, 2008). Exercises of market power typically include economic withholding (Harvey and Hogan, 2001; Olmstead and Ayres, 2014), physical withholding (MSA, 2012; 2015) and transmission related strategies (Jha and Wolak, 2015; FERC, 2012; FERC, 2013a; 2013b; 2013c).²

Market power arises in the generation segment of an electricity supply industry as a consequence of transmission limitations impeding competition geographically, ownership concentration of generators within limited import areas, the low elasticity of demand, and the non-storable nature of electricity (Joskow, 1997), as well as potential market design flaws, excessive reliance on spot markets, and vertical integration between transmission and generation possibly leading to exclusionary behaviour, among others (Joskow, 2008). In fact, achieving a sufficient degree of competition within the generation segment of an electricity supply industry requires an adequate number of competing firms geographically spread over the transmission network in such a way that the probability for local market power to arise out of transmission constraints remains reasonably low.

Therefore, facilitating entry of new firms into the generation segment of the industry is one of the keys to secure welfare-enhancing outcomes for electricity industry reforms. This is not a straightforward task because of the numerous and non-trivial restrictions to new competition applying to the power generation sector.

¹ PJM Interconnection is a regional transmission organisation in charge of the planning and management of the electricity grid infrastructures and the operations of the competitive wholesale electricity market in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.

² Economic withholding entails bidding capacity at very high prices so that it is not economically viable to the system except in extreme price periods. It is argued to allow generators to recoup their investment costs and other fixed costs (in response to the so-called "missing money" problem). Physical withholding can entail strategically timed outages (i.e. withholding of available capacity from the market) – e.g. in high demand periods to affect the market price. Transmission related strategies, can involve deliberately creating or increasing congestion of transmission grid nodes to increase prices.

This report investigates the patterns of entry in the generation segment of the electricity supply industry in 34 OECD countries,³⁴ and attempts to provide an understanding of its key determinants. The purpose of the paper is two-fold: to evaluate the important factors influencing the entry of new generators at the regional industry level, from new firms and incumbent firms, and to assess the determinants of entry into the different available generation technologies, more especially those based on renewable energy sources, so as to derive implications for the design of policies aimed at spurring competition in the electricity supply industry which are often subject to significant renewable energy objectives. We propose several hypotheses with respect to the important determinants of entry in different cases and test them empirically using a data set constructed from UDI's World Electric Power Plant Database.

Section 2 briefly reviews the potential barriers to entry, with a particular focus on the electricity generation industry. Section 3 presents the principal hypotheses to be tested. Section 4 describes the data used for the estimation of the econometric models presented in Section 5. Section 6 concludes. The Appendixes contains regression results as well as descriptive figures and tables.

2. The economic literature on entry, exit and market dynamics

Entry and exit have long been perceived as part of an error correction mechanism through which markets can adjust to equilibrium (Geroski, 1991). Tirole (1988) refers to the “Darwinian” selection of markets as a mechanism that transfers economic resources from the less efficient firms to the efficient ones.⁵ Other scholars have considered those processes as part of a “Schumpeterian” creative destruction process in which innovation is generated by the entrants, endowed with new technologies, which succeed to defeat incumbents and induce them to exit the market (Sönmez, 2013). Therefore, the survival of a firm is a signal for its efficiency.

In this context, barriers to entry can be seen as obstructing market dynamics. A barrier to entry or a “barrier to new competition” can be defined as “an advantage of established sellers in an industry over potential entrant sellers, which is reflected in the extent to which established sellers can consistently raise their prices above competitive levels without attracting new firms to enter the industry” (Bain, 1956). In other words a barrier to entry is any restriction on entry that allows incumbent firms to earn supra-normal profits.⁶

Cincera and Galgau (2005) provide a useful classification of the most important determinants of firm entry and exit. Firm-specific factors include the type, age and size of entrant, the firm's growth rate, the extent of excess capacity, the financial structure, past profits and adjustment costs among many others.

³ The dataset covers OECD countries at the time of writing this paper, i.e. 2015: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

⁴ The statistical data for Israel are supplied by and under the responsibility of the relevant Israeli authorities. The use of such data by the OECD is without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank under the terms of international law.

⁵ Note that the way a firm leaves the industry crucially affects the efficiency of the dynamics. While mergers and acquisitions allow preserving the production capacity within the market, voluntary liquidations and bankruptcies often lead to the capacity being removed from the market.

⁶ McAfee, Mialon and Williams (2004) propose nine alternative definitions for this term surveyed from the literature.

Industry-specific determinants encompass past entry and exit as well as the minimum efficient scale of production, capital intensity, resource intensity, the degree of maturity of the industry, concentration, innovation and differentiation. Finally, country-specific factors consist of the degree of economic development, macroeconomic shocks and access to capital. The authors further argue that an increase in the level of industry deregulation leads to an increase in both entry and exit rates. More generally, they consider that public intervention, through the implementation of a variety of market reforms, is one of the most important influencing factors of entry and exit decisions.

2.1. The economic literature on entry in the electricity generation market

Arguably, barriers to entry in electricity generation are particularly high. The empirical literature on market entry and exit in the generation segment of the electricity supply industry is quite limited, but identifies four types of interrelated barriers that may restrain entry:

- *Structural barriers* include high economies of scale, large capital requirements, high upfront sunk costs, long lead times, minimum efficient scales, absolute cost advantages, and very long asset lives (Kwoka, 2008; CEG, 2012). Even the fastest-built and least capital intensive types of power generators, such as gas-fired peaking plants, have lead times of around two years and capital costs of tens of millions dollars.⁷ Moreover, the necessity of additional transmission infrastructure in the face of entry may exacerbate those burdens by increasing lead times and capital requirements. Kwoka (2008) argues that absolute cost advantages accruing to incumbents may also exist. In particular, incumbent firms often possess the best locations for generation plants, which are obviously limited due to environmental, geographical, regulatory and other reasons. Further advantages to incumbents may come from policies such as fossil fuel subsidies (Kitson et al., 2011; OECD, 2012).
- *Regulatory or ‘institutional’ barriers* include environmental, land use and other regulatory requirements which are necessary for securing regulatory approvals, and as such induce non-trivial supplementary costs and delays to the entrant (Kwoka, 2008; Cichanowicz, 2008). The regulatory process related to grid connection of a new generator may entail high administrative burdens or be lengthy, in particular, when the regulator is already processing many projects. Further barriers may come from legislation on the shares of grid connection costs borne by the entrant.
- *Uncertainties about future prices and markets conditions* are particularly important for projects with very long time horizons like power plants but, effects may differ across generation technologies. They can be broadly classified into four, interrelated categories:
 - General “market risks” include risks related to entry itself, future demand and “cost risks”-uncertainties about future costs add to the picture if they heavily depend on particular inputs such as natural resources. Power generation from renewable energy sources is also subject to uncertainty due to dependence on meteorological conditions. The extent of lead times prior to entry is also hard to predict as it depends on multiple actors, in particular the delays associated with financing and securing regulatory approvals and leads to postponed revenue streams and increased investment risks. Investors will require a risk premium for financing such projects. Furthermore, Kwoka (2008) argues that capital investments in electricity generating facilities may be considered as almost entirely sunk, which magnifies the inherent

⁷ www.eia.gov/forecasts/aeo/assumptions/pdf/table8_2_er.pdf.

uncertainty and risks of investment since the capital cannot be redeployed to an alternative use and as such do not provide a viable fall-back position to investors.

- Risks related to public policies and regulations are due to unpredictable changes with, possibly, direct consequences on the profitability of both operating and prospective power generation projects. If the option value of waiting for policy or regulatory uncertainty to be resolved is large enough, investments will be delayed in time, if not - cancelled. Further, environmental policy uncertainty may have detrimental effects on investments in both fossil fuel power plants and renewable power plants. Therefore, regulation and support policies that are subject to abrupt changes may be disruptive to investors and project developers in general (CEG, 2012; Kwoka, 2008; Barradale, 2008; Kalamova et al., 2011; Johnstone et al., 2010). For instance, the uncertainty surrounding the carbon policy in Australia has been considered by market participants as a crucial factor causing the lack of investment in base load generation, in particular coal-fired power plants (Deloitte, 2011). On the other hand, the retroactive change of feed-in tariffs for solar photovoltaic power plants in Spain has led to the cancellation of many projects and the exit of numerous market participants.
- Infrastructure uncertainty can arise due to constraints on transmission capacity because of network congestions and strategic behaviours. In the face of uncertainty about future transmission availability, generators account for the probability of not being able to deliver. In addition, the economic viability of dispatchable power plants with sufficient ramping capacity is unlikely to increase along with the diffusion of intermittent renewable energy sources in the electricity mix, since they are increasingly used as complements to intermittent renewable plants – but may be crucial in determining the efficiency of investments in renewable energy generation (Benatia, Johnstone and Haščič, 2013).
- *Strategic behaviour* may arise in transmission grids operated by vertically integrated utilities. The adequacy of the transmission network as well as the unbundling of generation and transmission segments are therefore of crucial importance for spurring new entry. Strategic barriers to entry can arise from over-investment in generation capacity, pricing behaviour, contractual arrangements, reputational effects, network concentration effects, bundling, etc. It is, however, important to understand that not all behaviour that has the potential for deterring entry are adopted for that purpose. Also due to locational advantages, potential entrants may hence expect ‘tougher’ incumbents and thus a lower post-entry profitability. As such, absolute locational advantages have a strategic component since incumbents may want to prey on the best locations early on for reducing their costs as well as limiting entry. Strategic behaviour may arise particularly in transmission grids operated by vertically integrated utilities since they are subject to incentives for discriminatory practices among participants. The adequacy of the transmission network as well as the unbundling of the generation and transmission segments of the industry are therefore of crucial importance for spurring new entry.

3. Principal hypotheses

The decision of a firm to enter a particular market or market segment may be generally understood as a function of two economic factors: risk and return. Therefore, any element with a substantial effect on either one should be perceived as affecting entry decisions. That includes capital requirements and the extent of sunk costs, the minimum efficient scale of operation, the expected revenue streams, the access to financial markets, the current market structure, the policy and the regulation frameworks, the uncertainty surrounding future innovations, regulatory and policy reforms, among many others as reviewed in the introduction.

We study national markets for electricity generation, decomposing them into three sectors: green, brown and nuclear; themselves subdivided into subsectors (or technologies) according to their fuel type (e.g. green includes technologies such as wind and solar, see Table A1.1.). An entrant in this context is a ‘parent’ company that is associated with a new generating plant and has no prior installation of that technology in the country.

Entry may therefore be of two types: a *new entrant* is a new company that enters a country’s electricity generation industry for the first time by installing a new generator, or an *incumbent entrant* – an energy generator already present in the country in other technologies that is diversifying by investing for the first time in a particular technology. Multiple entries from a single company in the renewable industry are therefore possible and often observed for large firms. We also discuss *new plant entries*, referring to new plant installations, irrespective of the status of investors (incumbent or ‘true’ new entrant). The primary focus of this report is on the determinants of entry in the “green” subsectors of the electricity generation markets, i.e. those involving renewable energy sources for power generation.

In electricity supply, the regulation framework is one of the most important determinants of profits as well as of the existence of business opportunities. It determines the market structure to a large extent and thereby the potential degree of competition within the market. Different forms of regulation, from a liberalised industry to a vertically integrated public monopoly, imply more or less opportunities for new firms to enter the market. Anti-competitive regulation may impose various types of barriers to entry, some more drastic than others. Conway and Nicoletti (2006) propose several regulation indicators for the most important regulatory barriers to new competition in electricity sector.⁸ Their indicators attempt to measure the prevailing ownership structure of the electricity industry (from fully public to fully private), the extent of vertical integration across the generation and transmission segments, and across the industry as a whole, the degree of liberalisation in the retail segment, the existence and design of a wholesale market for electricity, and finally the conditions of a third-party access (TPA) to the grid. Regulated TPA, deregulated retail markets, liberalised wholesale power markets along with a private ownership structure in the industry are assumed to promote competition.

Moreover - as already established - incentives for anti-competitive behaviour arise if an electricity company simultaneously controls the transmission network as a monopolist and operates in the wholesale market. The company may earn supra-normal profit in the wholesale pool by discriminating access to its infrastructure that may appear as a simple reduction in service quality and thus be very difficult to evaluate by the regulator. The integrated monopolist may also embark in a cost-shifting strategy, i.e. to cross-subsidise its unregulated branch by shifting the costs of shared inputs to the regulated part of its business. Cost-shifting distorts competition and produces inefficiencies in the unregulated market of the industry as well (OECD, 2001). Also, administrative and institutional barriers affect entry decisions by imposing lags and costs to entrants, sometimes leading to long project lead times (Kwoka, 2008; Cichanowicz, 2008; Deloitte, 2011; CEG, 2012). According to the IEA (2011), non-economic barriers play just as important a role in shaping the cost of renewable energy projects and are judged more difficult to address than economic barriers. This leads to the first hypothesis (Table 1):

Hypothesis 1: Public ownership, vertical integration, the absence of regulated third party access and of competitive markets are associated with lower entry into generation subsectors.

The policy framework is a key determinant of entry decisions. In the electricity sector, policies can promote particular generation technologies by making them more attractive to investors. For renewable

⁸ Although some of those barriers may also have strategic and structural components, we name them ‘regulatory’ since they are erected by the regulator in the first place.

generation technologies, such policies typically include fiscal incentives (grants, rebates, tax credits, tax reliefs), public finance (investment, guarantee, loans), quantity-based instruments (renewable portfolio standards along with cap-and-trade schemes, e.g. renewable energy certificates), price-based instruments (feed-in tariffs and premiums), voluntary programmes (purchasing and labelling), grid access (priority dispatch, guaranteed access), and R&D support measures.⁹ Such policies aim at pulling market deployment by encouraging innovation and investment and consequently, can be expected to be associated with higher entry. This leads to:

Hypothesis 2: Renewable support policies are associated with higher entry into renewable energy-based generation subsectors.

In OECD countries, the prevailing market-based renewable support instruments are renewable energy certificates (REC) combined with quota obligations and feed-in tariffs (FIT). Quantity-based (e.g. REC) and price-based (e.g. FIT) economic instruments may be designed to achieve an equivalent outcome under perfect information, but the uncertainty around the shape of the marginal cost and the marginal benefit curves of pollution abatement generates important differences between the two instruments in real world applications. For instance, REC are often implemented allowing producers to choose among several technology options in order to comply with the obligation quotas, and can therefore encourage the development of the most cost-efficient technologies. On the other hand, FIT, often combined with guaranteed access, are generally perceived as more effective to spur growth in renewable energy deployment since they alleviate the risks borne by investors and lower the cost of capital, eliminating the risks associated with price fluctuations. Finally, the guaranteed contract terms of a FIT scheme enable a larger proportion of debt financing for renewable projects, which puts additional downward pressure on the cost of capital (Butler and Neuhoﬀ, 2008; Brer and Wstenhagen, 2009; Cory et al., 2009; Masini and Menichetti, 2012; Saveyn et al., 2008). As such FIT may hence be more attractive to new entrants, who may be more vulnerable to such uncertainties than incumbents:

Hypothesis 3: Feed-in-tariffs are associated with larger entry since they tend to provide greater stability and lower capital costs to investors than other market-based policies.

While policies and the regulation framework can mitigate investment risks and allow adequate returns in order to spur new competitive entry, factors related to market structure and technological features also have their importance.

Given differences in cost structures and level of maturity of the power generation technologies it is likely that the determinants of entry will vary by energy source. Mature energy sectors usually involve well-established incumbents and little room for new firms irrespective of the degree of competition. On the other hand, sectors in relatively early stages of development are unlikely to attract many firms until they exhibit sufficient returns:

Hypothesis 4: Both infant and mature technologies are associated with lower entry.

Power generation projects are highly capital-intensive, require long lead times and involve large fixed and sunk costs. In electricity generation, costs are almost entirely sunk, which exacerbates the risks of investment and poses a barrier to new entry (Kwoka, 2008; CEG, 2012):

⁹ Note that the design of policies and the political framework in which they apply are also important determinants of the renewable energy deployment outcome, and, of the total costs borne to achieve the environmental objective. Ill-designed policies may induce an inefficient allocation of capital towards some nominated technologies by crowding out the development of others and leading to lock-in (see Johnstone et al., 2010).

Hypothesis 5: Power-generating technologies that require larger amounts of capital are less likely to attract new firms.

Entry by new firms is almost always below minimum efficient scale of operation, i.e. the capacity of entrants does not allow minimising long-term average costs (Geroski, 1995; Kwoka, 2008). In practice this would imply that plants installed by new entrants will be of smaller capacity *ceteris paribus*:

Hypothesis 6: New plants installed by entrants are smaller than those installed by incumbents.

Barriers to entry in an industry are generally associated with higher concentration. Hindrances to entry may be due to industry concentration per se, through strategic behaviour of incumbents (e.g. excess capacity, cost and pricing strategies), economies of scale, absolute cost advantages or a first-mover advantage in new industries and technologies:

Hypothesis 7: Concentrated industries and technological niches may be associated with barriers to new competitive entry, and should hence exhibit lower entry rates.

One may also expect some form of path-dependency at the level of the firm. For instance, Kim (2013) finds that investor-owned electric utility companies in the United States that have previously invested in renewable generating assets are more likely to keep targeting their investment to the green power sector. In OECD countries, ‘mostly green’ firms tend to be highly specialised (Figure 1), notably more so than ‘mostly brown’ firms, suggesting the hypothesis of path-dependency in renewable subsectors:.

Hypothesis 8: There is a form of path-dependency and specialisation for renewable capacity investments, i.e. past experience with green technologies leads firms to a greater focus of their investment on renewable technologies.

Table 1. List of tested hypotheses

No.	Factors associated with degree of entry in electricity generation	Expected link with entry
H1	<u>(Lack of) Effective competition</u> : anti-competition regulation	(-)
H2	<u>Policy support</u> : Renewable energy support policies	(+)
H3	<u>Policy support</u> : Feed-in-tariffs	(+)
H4	<u>Technology</u> : least and most mature technologies	(-)
H5	<u>Technology</u> : higher capital needs of a given technology	(-)
H6	Investment size choice: entrants’ new plants are likely to be smaller	confirmation
H7	Market concentration	less entry
H8	Path-dependency and specialisation in RE: firms with experience in RE	confirmation

Figure 1. Capacity portfolios of electricity generating companies in OECD countries

Note: Counts of electricity companies, by type (share in %). UDI data contain 9913 electricity companies with installed capacity in OECD countries as of 2010, while only 1352 with installed capacity larger than 100 MW.

4. Data

The dataset used for estimating the econometric models presented in Section 5 has been constructed from UDI's World Electric Power Plant Database¹⁰ and supplemented with OECD statistics, OECD product market regulation indicators for the electricity industry (ETCR – energy, transport and communication regulation indicators) and policy measures from Johnstone et al. (2010) and Cárdenas Rodríguez et al. (2014). The dataset is initially built at the firm level over four dimensions: sector (i.e. green, brown, and nuclear), fuel type (e.g. wind, solar) country and time (see Table A1.1.).¹¹ It contains annual observations for 34 OECD countries from 1970 to 2010. However, we decided to restrict the sample to 1990-2007, primarily due to the nature of UDI data. The dataset is in fact not delivered in the form of actual time-series, but a snapshot of power plant units with historical information (e.g. year of entry, year of exit) provided. This allows a creation of a time series, but even if the data is of overall high quality, it means that the further the sample is extended, the higher the risks of inaccuracies. An additional reason is related to the fact that most of the deregulation of electricity markets in OECD countries took place during this period. Regulatory data was also only available to 2007.¹² UDI's data on exit contain a large number of missing dates of plant exit, which is why this study focuses on the patterns of entry rather than both entry and exit. However, statistical inference has permitted to obtain satisfactory estimates of

¹⁰ The data coverage is comprehensive for medium and large-sized power plants of all types, for utilities and independent power producers. Lower-scale plants such as wind turbines and solar PV systems are considered representative, including many facilities of less than 1 MW though most rooftop PV installations are neglected.

¹¹ Note that waste-to-energy is not considered as a renewable energy generation technology since it is difficult to assess the biomass fraction of inputs. We have also tested an alternative sector aggregation method by differentiating between old and new technologies for biomass and geothermal, as pointed out in Johnstone et al. (2010), and extract the small-scale projects for hydro and geothermal. It did not provide further insights on the tested hypotheses.

¹² Another reason to exclude years 2008 to 2010 is due to the possible complications due to the economic crisis. To build firm the dataset at the firm level, we follow the descriptive document provided by UDI which advises using the variable named "parent". However, this only provides information on the current parent of the company, not on the entire history, which may reflect privatisations and mergers and acquisitions.

missing exit dates for the entire dataset, and therefore to calculate the net cumulative capacity at the firm level by technology type and country. Note that if a country has never experienced entry in a particular technology over the whole period, no observation related to this technology is associated with the country in the final dataset. The panel is otherwise balanced.

4.1 Descriptive statistics on the electricity generation sector in OECD countries

Table 2 shows the average size of new plants, the number of plants added and total capacity by technology in OECD countries. To describe the state of the electricity generation industry in each OECD country over time and at various levels of aggregation, the Hirschmann-Herfindahl Index (HHI) of industry concentration, average vintage of generators, capacity penetration rates, regulatory indicators and policy measures have been constructed.

Table 2. Average size of new plants, capacity added and number of plants by subsectors

OECD countries						
	1990-2000			2001-2010		
	Average size of new plants (MW)	Number of plants added	Total capacity added (GW)	Average size of new plants (MW)	Number of plants added	Total capacity added (GW)
Biomass	5.87	703	3.985	5.58	1254	7.032
Geothermal	26.36	58	1.493	25.98	63	1.729
Hydro	24.07	1766	42.906	16.37	1874	31.059
Solar	2.06	161	0.112	2.257	2265	9.026
Wind	3.13	3173	11.261	23.55	4797	112.309
Coal	285.68	273	77.445	391.59	153	59.778
Gas	78.16	2022	158.196	175.45	1905	334.410
Nuclear	1113.48	45	50.388	1107.86	11	12.625
Oil	20.79	944	19.146	22.57	590	12.687
Waste	55.43	623	35.543	132.31	770	107.518

Source: aggregates derived from UDI Platts.

The Hirschmann-Herfindahl Index is the most widely used structural measure of concentration in a market, and is directly linked to market power in the theoretical Cournot model of competition.¹³ It is computed as the sum of squared market share (i.e. generation capacity share) of all firms, and ranges from 0 (perfectly competitive market) to 10,000 (monopoly). It has been rescaled from 0 to 100 in order to simplify the interpretation of the estimated coefficients. For the oil pipeline industry which has, similarly to the electricity industry, long been regulated, the United States Department of Justice considers that an HHI below 2,500 (i.e. 25 rescaled) indicates workable competition (Rose, 2007). Generally, an HHI that falls below 1,000 (i.e. 10) suggests a reasonably competitive market. High values of HHI are also found in new markets.¹⁴ Figure 2 shows the evolution of technology-specific HHI in Australia (left) and the country-level HHI for selected OECD countries (right).

¹³ Borenstein, Bushnell and Knittel (1999) discuss the weaknesses of the HHI and related concentration measures in the context of electricity markets, and provide an alternative methodology based on market simulation, which is not within the scope of this research.

¹⁴ A potential problem with these measures arises for countries composed of several segmented electricity markets like the U.S., Canada, Australia, etc. We have decided to report country-level estimations in this document,

Figure 2. Concentration indices for selected OECD countries

Source: derived from UDI Platts.

The average vintage of generation units is calculated as an average of the age of running generators at the levels of the country, sector and subsector, weighted by their respective generation capacity. We expect vintage to have various effects on entry, since it captures both the effect of a sector's maturity and that of the actual age of the fleet. A young fleet, with respect to the plant type's typical lifetime, may generally be associated with a growing technology, and therefore higher entry rates. On the other hand, an old fleet might attract investment, though not necessarily new entrants, if significant capacity retirements are to be expected. Figure 3 plots the average vintage of generators in Australia by technology type (left), and average vintage of all generators for selected OECD countries (right).

Figure 3. Average vintage of generators

Source: derived from UDI Platts.

although some work has been done with more disaggregated data and it appears that the significance of the estimates is not much affected.

In order to proxy for the effect of learning, innovation and maturity along time, we use the technology capacity penetration rates, which represent the total installed capacity of a technology type relative to total installed capacity in the country. For the less mature technologies, such rates can be expected to capture learning and innovation. For the mature technologies, such as large-scale hydro, it likely represents no more than the current deployment of the technology in a country. Figure 4 shows technology-specific capacity penetration rates in Germany (left) and the United Kingdom (right).

Figure 4. Capacity penetration rates of technologies in Germany and the UK

Note: Capacity penetration rates are presented as the share of a given technology in total available generation capacity.
Source: derived from UDI Platts.

Additionally, the dataset contains indicators of regulation of the electricity industry, based on the indicators of regulation in energy, transport and communication (ETCR), set as constructed by Conway and Nicoletti (2006). These are aimed at controlling for the effects of regulatory changes and major reforms of the industry structure. Regulation indicators include one for the extent of vertical integration across the transmission and generation segments (vertical integration), the ownership structure in the entire industry (public ownership), the presence of competitive markets and third-party access (entry), and an aggregate indicator accounting for all of those (electricity) – which is the regulation indicator actually used in our empirical analysis (labelled ETCR Regulation thereafter). Figure 5 presents an example of those indicators for Germany. Regulatory indicators are constructed on a 0 to 6 scale, where 6 means most anti-competitive regulation. The indicators are correlated across time we include solely the most comprehensive, aggregate electricity regulation indicator in the main estimations.

Figure 5. Regulation Indicators for Germany

Note: The indicators range from 0 to 6, where 6 is associated with the most anticompetitive regulation.
Source: OECD Product Market Regulation Database.

Measures of renewable energy support policies are based on Johnstone et al. (2010) and Cárdenas Rodríguez et al. (2014). We use binary variables for the presence of policies: policy support in general, feed-in tariffs, and renewable energy certificates. Continuous policy variables for the support levels of FIT (in US cent/kWh) and the targets associated with REC are also added (see Figure A1.2. in the Appendix). Interestingly, REC is consistently implemented in relatively more competitive industries and renewable policies and the electricity industry regulation in OECD countries have generally evolved in opposite directions.

Several measures of entry are considered to test the hypotheses set out in Section 3, including: capacity additions by entrants (in MW), number of plants added by entrants, capacity additions by entrants relative to total capacity additions (%) and number of plants added by entrants relative to total number of plants added (%). Figures 6 and 7 show the relative contribution of entrants to new installed capacity in the renewable subsectors (left), and the patterns of capacity additions of entrants and incumbents in the wind energy sector (right), in Germany and OECD as a whole. It appears that entrants participate relatively less to new capacity additions as the sector develops – in part due to an increasing number of incumbents. Therefore, it is likely that high capacity contribution rates of entrants will tend to be associated with less mature subsectors.

Figure 6. Relative contribution of entrants and wind capacity additions in Germany

Note: The relative capacity additions of new entrants are calculated as the share of capacity additions done by new entrants over total capacity additions, by technology, country and year.

Source: derived from UDI Platts.

Figure 7. Relative contribution of entrants and wind capacity additions in OECD countries

Source: derived from UDI Platts.

5. Model specifications and results

In order to test the hypotheses set out in Section 3, we consider several econometric models. All estimation procedures involve panel regressions with fixed-effects introduced with country and subsector dummies, and clustered standard errors. Also, we attempt to reduce potential endogeneity problems by introducing a one-year lag for all explanatory variables,¹⁵ except for real GDP growth and the indicators for renewable policies and electricity regulation, which are presumed to be sufficiently exogenous.¹⁶ An

¹⁵ As a robustness check, the models were also estimated with additional lags (two and three years). No significant difference was found.

¹⁶ Real GDP growth rates have been lagged in alternative specifications and results were almost identical. We have chosen to keep the current value so as to maximise the sample size.

economic motivation for using lagged variables is to consider the lead time between the investment decision and the actual construction of a power generator, which is inherently long in the electricity generation industry although renewable power plants have shorter construction time than conventional ones.¹⁷

Note that we are not able to control for unobserved time effects (through the introduction of a deterministic time trend or time fixed-effects) because of the strong negative correlation between time and the industry regulation indicator.¹⁸ In order to preserve the regulation variable in our specifications, we must implicitly assume that possible time trends in the dependent variables are entirely explained by our independent variables, in particular regulation, policies, vintage of plants and capacity penetration. This implies a need for cautious interpretation of the coefficients on the regulatory variable.

All models are estimated pooling all subsectors, for two reasons. First, pooling allows uncovering the common determinants of entry in the electricity generation segment rather than technology-specific factors that may not provide the desired general results. Second, it enables to greatly enlarge the number of observations in the dataset; which is highly desirable. All regressions focus exclusively on renewable technologies although the analysis could be extended to brown.

5.1. Drivers of entry

This section presents four econometric models of the determinants of entry decisions and entrants' absolute contributions in terms of generating capacity installed. More specifically, it attempts to sequentially determine the important factors of binary entry decisions (enter or not) and of the extent of entry (the size of new power plants installed by entrants) with a two-part model. Model (M1) is a logistic regression estimation of the likelihood of entry in renewable generation subsectors at the country level, i.e. the probability to observe at least one entry in each country's subsector. The second part, model (M2), evaluates the factors that affect the extent of entry, measured by capacity additions of entrants, providing that entry occurred. In addition, a variation of the capacity addition model (M2) is also estimated pooling all active firms, that is entrants and incumbents (M3). The motivation for this approach is to successfully disentangle the factors affecting entry decisions, the extent of entry and renewable plant entry in general. Two-part models are appropriate when the participation and contribution decisions are sequential.¹⁹ Finally, the capacity addition model (M2) is also estimated with micro-level data, i.e. at the firm level (M4), which is not as straightforward for the likelihood of entry (M1) model.

5.1.1 Likelihood of entry

We specify model (M1) as:

¹⁷ While constructing a coal-fired power plant can take up from 3 to 6 years, large wind generation plants take only about a year (Tegen, 2006). One-year lags are also in line with the methodology regarding the construction cost profiles of non-hydro renewables, for levelised-costs calculations in NEA/IEA/OECD (2015).

¹⁸ Pearson's correlation coefficients are found between -0.91 and -0.95 for all countries.

¹⁹ "Two-part models resemble the Heckman selectivity model, but do not include the inverse Mills ratio in the second part, and thus do not correct for selectivity. There is no latent variable representation for the two-part model. Instead it is motivated by a conditional mean independence assumption." Humphreys (2013). Unfortunately, estimating the enter-or-not model (M1) with all active firms is not possible since the dependent variable would exhibit nearly zero variance.

$$\begin{aligned}
\text{(M1)} \quad Y_ENTRY_{cft} &= \alpha + \beta_1 HHI_{cft-1} + \beta_2 CAPPEN_{cft-1} + \beta_3 VINTAGE_{cft-1} + \beta_4 ETCR_{ct-1} \\
&+ \beta_5 RENPOL_{cft-1} + \beta_{6t} GDPGROWTH_{ct} + u_c + v_f + \varepsilon_{cft}
\end{aligned}$$

The variable Y_ENTRY_{cft} was constructed to equal 1 if entry occurred in country c and technology f during year t , and 0 otherwise. Used as a dependent variable in model (1), this variable is expected to provide some information on the factors associated with larger probabilities of entry in a country's subsector. However, it does not take into account the extent of entry, which is the reason for specifying the second-part of the model (M2). The explanatory variables related to a country's subsector include the Herfindahl–Hirschman Index (HHI_{cft}), capacity penetration rates ($CAPPEN_{cft}$), and the average vintage of plants ($VINTAGE_{cft}$). Electricity industry regulation ($ETCR_{ct}$) is also included. $RENPOL_{cft}$ contains various measures of renewable energy policies targeting subsector s in country c , such as binary variables for the presence of renewable support policies, of feed-in tariffs, of renewable energy certificates, and continuous variables reflecting the levels of FIT and REC. Finally, the real GDP growth rate ($GDPGROWTH_{ct}$) is included to capture cyclical developments and fixed-effects (u_c , v_f) to capture unobservable both country-specific and subsector-specific heterogeneities which are time-invariant.

Results of the likelihood estimation are presented for a logistic approach only, since the probit regression gave similar estimates and, in the logistic case, odd ratios (i.e. exponentiated coefficients) ease the interpretation (Table A2.1 in Appendix II). Specifications excluding (columns 1,3 and 5) and including (2,4 and 6) geothermal and hydro; and with various ways to include information on renewable energy policies are presented.

As expected, policy and regulation appear to be important drivers of entry in “green” electricity generation. A one-point increase in the anti-competitive electricity market regulation indicator (ETCR) reduces the probability of observing entry in green subsectors during the year by up to 20% (in line with *Hypothesis 1*). It seems that regulation has a slightly stronger entry-deterring effect for biomass, wind and solar than for hydro and geothermal.

Renewable support policies (RENPOL) have large positive effects on the likelihood of entry (*Hypothesis 2*). The presence of feed-in-tariffs is associated with larger probabilities of observing entry than the general presence of support policies, whereas renewable energy certificates are only estimated significant when excluding hydro and geothermal subsectors. Considering the results for the restrained set of renewable energy sources, policy support is estimated to increase the likelihood of entry by 180%, while 328% for FIT and 185% for REC. Additionally, a one US cent increase of the FIT level is assessed to increase the likelihood of entry by around 3%, whereas REC targets are found with no significant effect. These results suggest that feed-in tariffs may have had an overall larger entry-inducing effect than renewable energy certificates and other types of policy support, possibly due to limiting the risk on the producers' side (*Hypothesis 3*), but part of the result may be due to difference in strength of the two types of instruments.

The coefficient of concentration measures (HHI) is not statistically significant when hydro and geothermal entries are included. Subsector concentration reduces the likelihood by around 0.5% for each unit increase when these are excluded. That is, from a mild concentrated industry (25) to a competitive one (10) the probability of observing entry during the year would be nearly 8% larger, suggesting that market concentration may work as a barrier to entry in relatively less mature and less capital-intensive subsectors (i.e. when excluding hydro and geothermal), but requires some caution as new industries tend to exhibit high HHI values. On the other hand, some issues of multi-collinearity (higher levels of concentration linked with higher anti-competitive regulation) may mean that the significance of the effect is underestimated.

Capacity penetration rates (CAPPEN) and average vintage of units (VINTAGE) are found with a positive effect or not statistically significant depending on which subsectors are included in the regression. Even though the two variables are fairly correlated, the estimates are not affected when any of the two is excluded from the regression. Entry appears more likely in more developed subsectors, by around 4% per percentage point of penetration, but this result seems driven by the inclusion of hydro and geothermal. Average vintage of units is associated with a 5% increase in the likelihood of entry in the biomass, solar and wind subsectors for each additional year. In both cases, it may be related to an “experience effect” that is positively linked with entry probabilities. The results suggest that more developed subsectors are more likely to attract new entrants, probably because previous projects have already paved the way to (other) new entrants in terms of regulatory processes, access to finance, administrative procedures, and other impediments, but also because of the availability of better technologies.

There is no evidence that entry in renewable subsectors is cyclical. At the same time, entry likelihood depends on subsector: entry in wind energy is found to be up to 300% larger than in the biomass subsector, whereas entries in hydro, geothermal and solar subsectors are less than half as likely as for biomass. These results provide further insight regarding our expectations on the effects of technology maturity and capital requirements. Over the period studied, 1990 to 2007, wind energy was the fastest-growing renewable energy source in OECD countries and is naturally found associated with a higher probability of entry, confirming that growing sectors tend to be associated with the presence of new investors. Biomass-fired generation capacity also increased, although at a lower rate. In general, hydro and geothermal power generating projects rely on relatively mature technologies, and should therefore be expected as less attractive to entrants. On the other hand, solar was still disparately deployed during the period of the analysis, since solar technology deployment really took off in 2007, a finding in line with *Hypothesis 4*, which claims that infant subsectors, as well as very mature ones are unlikely to exhibit a lot of entry.²⁰

The same models were also run with interactions between renewable energy policy variables and regulation indicators. Table A2.6, columns (1) and (2), in the Appendix reports estimates when interacting the continuous policy variables with a binary variable for anticompetitive regulation.²¹ The only important result found seems to be that FIT have twice as large marginal effects on entry in more regulated industries as in liberalised industries, though only at the 10% significance. Note that this result is entirely caused by the inclusion of solar entries in the sample, hence fragile. In fact, there is some correlation between the constructed dummy for regulation and time (with Pearson’s correlation coefficient of -0.46, also the median year when dummy equals 1 is 1997 while 2004 when equals 0). As depicted by Figure 8, solar power feed-in tariffs are significantly higher towards the end of the sample, which are associated with larger probability of having ‘at least one entry’. Therefore, the estimates mean that the probability of the first entry in the solar subsector has not been affected much by the increase in FIT, which usually happened after. At the same time one may expect that the increase in FIT has affected the actual magnitude of entry as will be seen later in the text.

²⁰ Over the period 1990- 2010, wind generation capacity grew by a factor 51 in OECD countries, 1.05 for coal, 2.45 for gas, 1.47 for geothermal, 1.17 for hydro, 0.98 for nuclear, 0.74 for oil, 16.79 for solar, 9.06 for waste.

²¹ The binary variable for regulation was coded 0 for any value of the regulation indicator below 2, and coded 1 if between 2 and 6. In general, industries associated with an indicator below 2 have significantly lower concentration indices than those with indicators above 2 (see appendix). Other models with dummy policy variables interacted with the continuous regulation indicator were estimated though did not provide further insights.

Figure 8. Polynomial time trends of Probability of Entry and FIT: Wind (left) and Solar (right)

Note: Probability of Entry refers to the average of (M1)'s binary dependent variable. Time trends are estimated as the average of the dependent variable of (M1), respectively FIT values, pooled across countries for each technology, and smoothed using a 5th order polynomial along the time period.

5.1.2 Determinants of renewable capacity additions of entrants

We now turn to the second part of the estimation. Model (M2) is specified with a similar approach than for model (M1). The dependent variable is the logarithmic transformation of strictly positive capacity additions of entrants in the renewable subsectors ($\log(ENTRANTSMW_{cft})$) while the explanatory variables remain unchanged. The ordinary least squares estimates for the pooled regression with fixed-effects and clustered standard errors are presented in Table A2.2.

$$\begin{aligned}
 (M2) \quad & \log(ENTRANTSMW_{cft}) \\
 &= \alpha + \beta_1 HHI_{cft-1} + \beta_2 CAPPEN_{cft-1} + \beta_3 VINTAGE_{cft-1} + \beta_4 ETCR_{ct-1} \\
 &+ \beta_5 RENPOL_{cft-1} + \beta_6 GDPGROWTH_{ct} + u_c + v_f + \varepsilon_{cft}
 \end{aligned}$$

Results are similar to those of the first-part regressions since policy and regulation still appear to be crucial determinants of entrants' capacity additions in the green sector. A one point increase in the anti-competitive electricity regulation indicator (ETCR) reduces entrants' new capacity by more than 20%, with a significantly larger effect for biomass, wind and solar (*Hypothesis 1*). Renewable support policies are estimated with large positive effects (*Hypothesis 2*). While REC are consistently associated with larger capacity additions than FIT (*Hypothesis 3*), the latter are found with a coefficient of much lower magnitude in the large sample, which can be due to the limited use of FIT in the hydro and geothermal subsectors. Leaving that aside, the presence of FIT is associated with around 70% larger capacity additions while nearly 110% for that of REC. On the other hand, a one US cent increase of the FIT level is assessed to increase capacity additions by around 3%, whereas REC targets are not found significant. These results suggest that feed-in-tariffs and renewable energy certificates may have fairly similar effects on the magnitude of entry when adequately adjusted, in accordance with the literature on economic instruments.

The coefficient of concentration measures (HHI) is estimated with a negative effect of around -0.6% per unit increase, i.e. the volume of renewable capacity additions of entrants increases by 9% from a mild concentrated industry (HHI around 25) to a competitive one (HHI around 10). However the coefficients are not consistently significant across the specifications and should hence be taken cautiously. Capacity penetration rates (CAPPEN) are found with a positive effect, varying across samples. The effect seems much stronger for growing subsectors, could be related to the effect of learning and innovation. In line with

previous findings, this suggests that more developed subsectors are more attractive to new entrants. Even though maturity may be expected to have detrimental effects on entry after a certain threshold, a one-year increase in average vintage of generators (VINTAGE) is associated with 5% larger installations of entrants when neglecting hydro and geothermal capacities. This result confirms the importance of innovation and learning-by-doing for growing subsectors, which are expected to be jointly captured by the two variables in the smaller sample.

Subsector dummies have significant effects on entrants' capacity additions, each representing the typical size of the plants added by entrants in each subsector relative to that of biomass. Table 3 summarises average plant sizes by category. Kernel density plots are to be found in Appendix I.

Table 3. Average size of a new installation added by technology type and firm type (MW)

	New Entrants	Incumbent-entrants	All firms	All entrants (new and incumbent-entrants)	Incumbents
Biomass	4.6 (1.4)	9.7 (2.6)	7.1 (2.1)	5.9 (1.6)	9.1 (3.2)
Geothermal	12.9 (5.5)	11.7 (7.5)	34.3 (26.3)	12.4 (6.5)	40.6 (30.0)
Hydro	3.8 (0.7)	37.7 (1.8)	24.9 (1.7)	6.2 (0.8)	36.3 (3.0)
Solar	4.2 (1.1)	2.8 (0.2)	5.0 (1.0)	3.9 (1.0)	7.1 (1.5)
Wind	6.6 (0.9)	22.4 (4.6)	21.5 (3.0)	8.1 (1.0)	38.6 (10.2)

Note: Median values in parenthesis. Incumbent-entrant is a firm that has generation in that country, but is new in the given technology.

Source: values derived from Platts UDI data.

Incumbents tend to install significantly larger plants than entrants. It suggests that entry costs include a component varying with the plant size. Specifically, we can expect uncertainties and regulatory barriers to impose entry costs that increase with the plant size, thereby leading new investors to choose smaller capacity than incumbents in equilibrium. On the other hand, the discrepancy could also be related to strategic overinvestment from incumbents, so as to deter entry for example. It appears that new entry occurs below the average and median plant scales for all renewable energy sources.²² Incumbent entrants, i.e. those with previous installations of any other technology in the country, seem less affected by this phenomenon although they also appear to invest in smaller plants than incumbents. The estimated kernel density functions shown in Figure A1.3. confirm that new entrants are generally associated with smaller capacity additions than incumbent-entrants (i.e. diversifying incumbents) and incumbents, for all technologies, except solar. Diversifying incumbents also tend to install smaller plants than incumbents, but the difference appears much less important. These findings support *Hypothesis 6*.

Similar models with interacted policy variables and regulation indicators do not provide further insights. Neither FIT nor REC are found with significantly different marginal effects on capacity additions of entrants across the regulatory regimes, confirming the expectation that the estimates of the first-part models with interactions were likely misleading. The increase in FIT that occurred in liberalised countries have actually induced more capacity additions of entrants, meaning that it has affected the volume of entry, although with marginal effects similar to those in 'more regulated' industries.

²² This phenomenon seems larger for hydro and geothermal, which is most likely due to the growing significance of small-scale power generation projects based on those energy sources. It is therefore possible to refine the estimates of this study by neglecting all hydro and geothermal projects larger than a predefined threshold (which could be fixed at 5 MW for small-scale geothermal and 10 MW for small-scale hydro).

5.1.3 Factors influencing the size of capacity additions of all firms

This subsection presents the counterpart of model (M2) with capacity additions of all firms (entrants and incumbents), as formally defined by equation (M3).

$$(M3) \quad \log(MW_{cft}) \\ = \alpha + \beta_1 HHI_{cft-1} + \beta_2 CAPPEN_{cft-1} + \beta_3 VINTAGE_{cft-1} + \beta_4 ETCR_{ct-1} \\ + \beta_5 RENPOL_{cft-1} + \beta_6 GDPGROWTH_{ct} + u_c + v_f + \varepsilon_{cft}$$

Results presented in Table A2.3 suggest that deregulation positively affects the volume of renewable capacity additions, although only for the growing subsectors and to a lower degree than for entrants. The concentration index also seems to be associated with lower values of the dependent variable and the magnitude tends to be larger than when considering only entrants. Capacity penetration rates are estimated with two-fold larger effects than for entrants, while vintage of generators is not found of great significance. Renewable policies are estimated with similar effects to those obtained with entrants only, except for the support policy dummy - which is found with larger effect in this model. Subsector dummies have different coefficients than previously, implying that the relative size of capacity additions in each subsector changes when considering incumbents in the model. Altogether, incumbents and entrants respond differently to changes in the explanatory variables. Capacity additions of incumbents seem less affected by regulation, although concentration and capacity penetration are found of higher magnitude. It may be understood that as the pool of incumbents grows and renewable technologies are further deployed, country-level renewable capacity additions increase. Overall, those results cannot be readily interpreted without going down to the analysis of micro-level data.

5.1.4 Micro-level data: Determinants of firm-level renewable capacity additions

The next model considers micro-level data. It is not obvious which firms should be defined as a potential entrant for a given subsector and which should not. One solution is to consider that all firms present in a country are potential entrants for all subsectors. However this assumption is strong and such model would hardly fit the data. Therefore, studying the likelihood of entry at the level of the firm raises structural issues that need to be properly addressed (Reiss and Wolak, 2007).

In order to abstract from any issue related to picking the right definition of potential entrants through an ad-hoc distribution that would affect our estimates to a large extent or could render the model intractable, we consider the population of all renewable plant entries over the period 1990-2007 and look for the significant explanatories of the size of those capacity additions at the (parent) firm-level, providing they are strictly positive and that all firms involved have prior installations in the country.²³ The model is specified as follows:

$$(M4) \quad \log(MW_{cpft}) \\ = \alpha + \beta_1 HHI_{cft-1} + \beta_2 CAPPEN_{cft-1} + \beta_3 VINTAGE_{cft-1} + \beta_4 ETCR_{ct-1} \\ + \beta_5 RENPOL_{cft-1} + \beta_6 GDPGROWTH_{ct} + \beta_7 GREENSHARE_{cft-1} \\ + \beta_8 GREENSHARE_{cpt-1} + \beta_9 D_UTILITY_{cpt-1} + \beta_{10} D_SIZE_{cpt-1} \\ + \beta_{11} D_ENTRANT_{cpt-1} + \beta_{12} MARKETSHARE_{cpt-1} + \beta_{13} PORTFOLIOCONC_{cpt-1} \\ + u_c + v_f + \varepsilon_{cft}$$

²³ The reason to focusing on capacity additions of firms with prior installations is to avoid important collinearity issues arising out of the inclusion of the binary variable ‘being a new entrant’ and the continuous variables for portfolio concentration, market share and share of green at the level of the firm.

The model is thus the same as model (M2) and (M3), with some additional variables, such as the share of renewable capacity installed in the country ($GREENSHARE_{ct}$), a dummy for renewable portfolio standards policy (RPS Policy) and a set of parent companies' characteristics. This set contains three dummies, $D_UTILITY_{cpt}$, D_SIZE_{cpt} and $D_ENTRANT_{cpt}$, which respectively equal 1 when the firm, is a utility company, has total installed capacity larger than 100 MW, and is an entrant, and 0 otherwise. There are also three continuous variables, the share of renewable capacity owned by the parent company p ($GREENSHARE_{cpt}$), the market share of the firm ($MARKETSHARE_{cpt}$, measured in terms of owned generation capacity relative total installed capacity in the country) and a measure of portfolio concentration ($PORTFOLIOCONC_{cpt}$, built similarly to Herfindhal's index with technology-specific capacity shares at the firm level). Results are reported in Table A2.4.

Results confirm the negative effects of industry concentration and electricity regulation. It appears that regulation also has a stronger effect for fast-growing subsectors in this model. Moreover, the magnitude of the coefficients of the industry regulation indicator is consistently larger than when estimated with aggregates.

Renewable support policies have lower coefficients than when estimating using country-level data. The dummy for the presence of RECs is not found significant, whereas the targets of RECs are evaluated of rather large magnitude, i.e. a 6% increase in the dependent variable per additional percentage point. However, their interpretation is different here since we are looking at firm-level capacity additions and not aggregates. The effect of renewable policies on annual country-wide capacity additions is two-fold. As seen in model (M1), policies deliver incentives to invest in the technologies, implying that an increasing number of firms will eventually invest in the sector. On top of that, as shown by model (M4), firms that do invest tend to invest more as a result of policies. Therefore, it is not surprising that renewable policies have larger effects on annual capacity additions at the country level than at the level of a firm, because of the 'volume effect'.

Capacity penetration rates are estimated positive and of large magnitude. In the smaller sample, firm-level capacity additions are estimated to increase by about 6% for each additional percentage point of capacity penetration, meaning that the more a subsector is developed in a country's electricity industry, the larger the average size of new plants is. On the other hand, vintage seems to negatively affect the size of new plant entry, which contradicts our previous estimates, but may be due to the focus on incumbent-entrants.

Countries with a higher green 'energy' share tend to be associated with larger firm-level capacity additions. The result is likely driven by the inclusion of hydro capacity additions. This naturally implies that in countries with large hydropower generation capacity firms invest more in larger hydropower capacity than elsewhere. Interestingly, experience with green technologies, as measured by the share of green capacity owned by the firm, is consistently found with positive coefficients. It suggests some form of path-dependency and specialisation of 'green' investment at the firm level, consistent with Kim (2013), i.e. companies that have past experience with renewable technologies are more likely to step up their investment in such technologies.

While larger firms are found to install twice as more capacity at a time, utilities are associated with 30% smaller capacity additions for the fast-growing renewables than independent power producers. Large independent power producers may hence be considered as important contributors to the development of those renewable energy sources in the electricity sectors of OECD countries. The share of capacity installed in a country that is owned by a specific company, defined as the market share of the firm, is found with a positive coefficient, suggesting that well-established firms undertake larger projects.

Finally, the portfolio concentration of a firm is assessed to negatively affect the size of new power generation installations based on biomass, solar and wind energy sources, indicating that the more specialised a firm is the smaller the biomass, solar and wind projects she undertakes tend to be. The reason for this is two-fold. First, the size of firms is fairly related to its degree of specialisation and, as previously pointed out, smaller firms tend to invest in smaller projects. Also, Figures A2.3 and A2.4 in the Appendix depict the relationship between portfolio concentration and the actual share of renewables in the portfolio of firms, according to their size. It clearly appears that firms with high specialisation in the green energy sector also tend to focus their investment on a narrow portfolio of technologies irrespective of firms' size. Moreover, 66% of observations are associated with shares of green capacity larger than 75% while 26% of them are associated with shares lower than 25%, implying that most of capacity additions in the sample comes from sector-oriented firms, most of them being towards the renewable generation industry. Hence, the result would rather suggest that although renewable-oriented power generating companies undertake larger renewable projects, their specialisation is often linked to a relatively limited portfolio of technologies with negative effects on projects' size, giving additional evidence in support of the existence of path-dependency in capacity investments.

5.2. Determinants of the relative participation of entrants

We now attempt to uncover the factors affecting the relative contribution of entrants to new capacity additions in the renewable electricity sector. Model M5 investigates on the capacity additions of entrants relative to total capacity additions in MW, i.e. the relative contribution of entrants to new capacity installed. Observations associated with the first entry in every country's subsectors have been dropped since they are likely to be influential (the dependent variable naturally equals 1 for every first entry).

$$(M5) \quad \frac{ENTRANTSMW_{cft}}{TOTALMW_{cft}} = \alpha + \beta_1 HHI_{cft-1} + \beta_2 SHARE_{cft-1} + \beta_3 VINTAGE_{cft-1} + \beta_4 ETCR_{ct-1} + \beta_5 RENPOL_{cft-1} + \beta_6 GDPGROWTH_{ct} + u_c + v_f + \varepsilon_{cft}$$

The set of independent variables remains similar to that of models (M1) to (M3). Table A2.5 presents the estimation results obtained with ordinary least squares.²⁴

The results show that higher contribution rates occur in less mature and less competitive industries. The indicator of electricity industry regulation, as well as the concentration index, are found with positive effects on contributions of entrants, which is caused by the slower pace at which incumbents install new capacity because of the smaller number of incumbents in more concentrated industries, with naturally higher degrees of regulation. Entrants are simply more likely to install new plants in a period with no additions from incumbents, which artificially increase the contribution rates in regulated industries.²⁵ Furthermore, in the presence of strong anti-competitive regulations, the protected incumbents may be less dynamic and less likely to respond to new opportunities, as for instance in renewable energy. Therefore,

²⁴ The dependent variable being a proportion, a generally more appropriate statistical approach is to use a generalised linear model with a logit link and the binomial family, i.e. a fractional logit model as proposed by Papke and Wooldridge (1996). See also Buis (2006) for STATA implementation. The OLS approach reported here gives impossible predictions, since fitted values cannot be constrained as 'proportions' and has other caveats, although it provides satisfactory estimates and has the valuable advantage to be more readily interpretable.

²⁵ Pearson correlation coefficients between computed six-year moving average frequencies of capacity additions by incumbents and regulation indicators strongly support this interpretation. We find that frequency is negatively correlated with regulation up to -0.97 for biomass, 0.86 for geothermal, -0.55 for hydro, -0.93 for solar and -0.96 for wind.

stricter forms of regulation cannot be viewed as intensifying the entrants' participation to the renewable energy deployment effort, although their relative contributions appear significantly larger in less competitive markets.

The dummy for renewable support policies is not significant, whereas those for feed-in-tariffs (FIT Policy) and renewable energy certificates (REC Policy) are found positive, though only significant at 10% for REC. Results indicate that the presence of REC have had smaller effects on the contribution of entrants than FIT, +7% against +12%. Also, an increase of one US cent of FIT is evaluated to add 0.4% to the dependent variable for the fast-growing renewables whereas REC targets are never found significant.

The average vintage of units is estimated to increase contribution rates of entrants by around one percentage point per additional year. From models (M2) and (M3), it appears that capacity additions of entrants are positively affected by vintage of units whereas those of incumbents are not. On the other hand, a one percentage point increase in capacity penetration rates is evaluated to reduce contributions by up to two percentage points in the smaller sample, while ten times less when all renewables are pooled. Results indicate that contributions of entrants in less mature subsectors are more sensitive to capacity expansion. It should be understood that an expanding subsector would inevitably exhibit lower participation rates of entrants at some point. Large capacity expansion may generally be associated with a larger number of incumbent firms, implying higher pace of capacity installations. Sustained contribution rates would hence require increasingly larger volumes of new capacity additions of entrants that can hardly be met.

Finally, subsector dummies provide further evidence of generally higher contribution rates in less mature sectors with lower capital requirements. Hydro and geothermal are associated with the lowest rates while the solar dummy is associated with the highest ones. Participation rates for biomass and wind, the two subsectors in growing stages during the period of study, are found closer to those of solar, although about 20% lower, than those of hydro and geothermal. We consider this in line with *Hypothesis 5*.

Model (M5) was also estimated with interacted variables as reported in the Appendix (see Table A2.7). Findings provide further insights on the relationship between policies and regulation in this context. First, REC appear as negatively affecting contribution rates in regulated industries although this is misleading since such result comes from the fact that almost no REC have been implemented in more regulated industries (see Figure A1.1. in the Appendix). Also, regulation is found to have a significantly lower impact on contribution rates in the presence of feed-in tariffs. This suggests that the implementation of FIT has contributed to reduce the fall in capacity contribution rates of entrants provoked by the gradual liberalisation of the electricity supply industry. In other words, in the absence of FIT or equivalent support policies entrants may be expected to contribute to new capacity additions at much lower rates in competitive markets, as new capacity will tend to be increasingly installed by incumbents (Figure 9). One plausible reason for this effect is that FIT have generally been successful at attracting small investors into the renewable energy sector (e.g. wind power community projects in Europe). Therefore, environmental policies and industry policies may be considered as complementary means of inducing entry and sustaining the participation of entrants to renewable capacity expansion in more competitive industries.

Figure 9. Predicted contribution rates for industry regulation adjusted by FIT Policy

Note: Contribution rates refer to (M5)'s dependent variable. Marginal effects are computed at means from the model presented in column 7 of Table A2.7 in the Appendix. The horizontal axis gives the value of the indicator of anti-competitive regulation in the electricity sector (based on ETCR). Value 6 means most regulated, value 0 most liberalised. POLICY_FIT equals to 1 means FIT are implemented. The vertical lines show 95% confidence intervals.

6. Conclusion

This report provides an analysis of the patterns of “new” entry in the generation segment of the electricity industry, with a strong focus on renewable energy-based technologies. Several important findings are highlighted below.

Industry (de)regulation and renewable support policies are estimated as the most important determinants of entry in the electricity generation sector. Structural deregulation and the introduction of competitive electricity markets along with renewable support policies are always found to be associated with higher likelihood and volumes of entry (*Hypothesis 1*). Although capacity additions of incumbents also respond to policy incentives, they seem relatively less affected by the regulatory framework.

The two forms of market-based instruments to support renewable electricity generation (FIT and REC) considered in the analysis have important entry-inducing effects, often larger than other policy support instruments (*Hypothesis 2*). Feed-in tariffs are consistently found to have greater positive impacts on entry and capacity investments than renewable energy certificates (*Hypothesis 3*). Though this result might be influenced by the wider implementation of FIT policies, it provides some support of the premise that FIT tend to provide greater foreseeability and increased returns on investment. Therefore, any policy objective oriented towards the deployment of renewable energy in the power generation industry, must consider environmental policies and industry policies as complementary parts of a common policy framework.

Higher rates of entry as well as larger volumes of capacity installed by entrants may be typically expected in developing subsectors, due to greater technological innovation, learning and increasing efficiency, accordingly with the industrial organisation literature (*Hypothesis 4*). Unsurprisingly, the participation of entrants in the installation of new capacity in a country decreases with sectoral expansion as the pool of incumbent firms grows and technologies become more mature.

The contribution of entrants to new capacity additions is found significantly higher for technologies with smaller capital requirements and larger deployment rates (*Hypothesis 5*). Moreover, while larger and

well-established firms tend to undertake larger projects, new entrants appear to get involved in significantly smaller projects (*Hypothesis 6*), and to target investments into fast-developing technologies, suggesting there may be inertia with regards to conventional power generation technologies.

Incumbents are more likely to add capacity than entrants in more concentrated industries (*Hypothesis 7*). The presence of sector concentration often goes along with that of barriers to new competitive entry, even though infant sectors obviously exhibit high degrees of concentration. We find that concentration has detrimental effects on the likelihood and the volume of entry as well as the relative contribution of entrants, which may be related to the existence of an absolute cost advantage or other strategic and structural barriers that would require case studies to be rigorously identified.

Finally, we find evidence in support of path-dependency related to ‘green’ capacity investments (*Hypothesis 8*). Firms with prior installations involving renewable technologies are generally associated with larger renewable projects although they tend to focus on a relatively narrow portfolio of generating technologies. In fact, the gradual liberalisation of electricity industries along with the implementation of renewable policy support has led to the outburst of technology-specialised ‘fully green’ small companies in the generation segment of electricity industries that represented almost 50% of total renewable energy-based capacity additions in 2010.

Achieving a satisfactory degree of competition in the power generation markets in parallel of renewable energy goals will require taking advantage of the complementarities between environmental policies and industrial policies, in particular through their effects on spurring new entry in renewable-based generation capacity.

REFERENCES

- Aguirregabiria, V. (2012), “Empirical Industrial Organization: Models, Methods, and Applications”, University of Toronto, Preliminary version.
- Bain, J. (1956), *Barriers to New Competition*, Harvard University Press, Cambridge, Massachusetts.
- Barradale, M.J. (2008), “Impact of policy uncertainty on renewable energy investment: Wind power and PTC”, USAEE Working Paper 08-003.
- Benatia, D., N. Johnstone and I. Haščić (2013), “Effectiveness of Policies and Strategies to Increase the Capacity Utilisation of Intermittent Renewable Power Plants”, *OECD Environment Working Papers*, No. 57, OECD Publishing, Paris, <http://dx.doi.org/10.1787/5k46j0trlrnn-en>.
- Berry, S. and Peter Reiss (2007), “Chapter 29 Empirical Models of Entry and Market Structure”, *Handbook of Industrial Organisation*, Vol. 3, pp. 1845–1886.
- Borenstein, S., Bushnell, J., & Knittel, C. R. (1999). Market power in electricity markets: beyond concentration measures. *The Energy Journal*, 65-88.
- Borenstein, S., Bushnell, J., & Wolak, F. (2002). Measuring Market Inefficiencies in California's Wholesale Electricity Industry. *American Economic Review*, 92(5).
- Buis, M. L. (2006), “Modeling for Response Variables That Are Proportions”, United Kingdom Stata Users' Group Meetings 2006 15, Stata Users Group.
- Bürer, M.J. and R. Wüstenhagen (2009), “Which renewable energy policy is a venture’s capitalist’s best friend? Empirical evidence from a survey of international cleanth investors”, *Energy Policy*, Vol. 37, pp. 4997-5006.
- Butler, L. and K. Neuhoﬀ (2008), “Comparison of Feed in Tariff, Quota and Auction Mechanisms to Support Wind Power Development”, *Renewable Energy*, Vol. 33/8, pp. 1854–67.
- Cichanowicz, J.E. (2008), “Discussion and Examples of Entry Barriers in the Electricity Generation Market”, Report to the American Public Power Association.
- Cincera, M. and O. Galgau (2005), “Impact of Market Entry and Exit on EU Productivity and Growth Performance”, European Commission, Directorate-General for Economic and Financial Affairs, Economic Papers, No. 222.
- Competition Economists Group (CEG) (2012), “Barriers to Entry in Electricity Generation”, Report for the AEMC.
- Conway, P. and G. Nicoletti (2006), “Product Market Regulation in the Non-Manufacturing Sectors of OECD Countries: Measurement and Highlights”, *OECD Economics Department Working Papers*, No. 530, OECD Publishing, Paris, <http://dx.doi.org/10.1787/362886816127>.
- Cory, K., T. Couture and C. Kreycik (2009), “Feed-in Tariff Policy: Design, Implementation, and RPS Policy Interactions”, Technical Report NREL/TP-6A2-45549.

- Cárdenas Rodríguez, M., et al. (2014), "Inducing Private Finance for Renewable Energy Projects: Evidence from Micro-Data", OECD Environment Working Papers, No. 67, OECD Publishing, Paris, <http://dx.doi.org/10.1787/5jxvg0k6thr1-en>.
- Deloitte (2011), "Electricity Generation Investment Analysis", Final Report.
- FERC (2012), Constellation Energy Commodities Group, Inc., 138 FERC ¶ 61,168. March 9, 2012.
- FERC (2013a), In re Make-Whole Payments and Related Bidding Strategies (JP Morgan Ventures Energy Corporation), 144 FERC ¶ 61,068. July 30, 2013
- FERC (2013b), Barclays Bank PLC, et al., 144 FERC ¶ 61,041. July 16, 2013.
- FERC (2013c), Deutsche Bank Energy Trading, LLC, 142 FERC ¶ 61,056. January 22, 2013.
- Geroski, P. A (1991), *Market Dynamics and Entry*, Blackwell, Oxford.
- Geroski, P. A. (1995), "What do we know about entry?", *International Journal of Industrial Organization*, Elsevier, Vol. 13/4, pp. 421-440.
- Harvey, S. M., & Hogan, W. W. (2001). Market power and withholding. *Harvard Univ., Cambridge, MA*.
- Humphreys, B. R. (2013), "Dealing With Zeros in Economic Data", University of Alberta, Department of Economics.
- IEA (2011), *Deploying Renewables: Best and Future Policy Practice*, OECD Publishing, Paris, <http://dx.doi.org/10.1787/9789264124912-en>.
- IEA (2005), *Lessons from Liberalised Electricity Markets, Energy Market Experience*, OECD Publishing, Paris, <http://dx.doi.org/10.1787/9789264109605-en>.
- Jha, A., & Wolak, F. A. (2015). Testing for Market Efficiency with Transaction Costs: An Application to Financial Trading in Wholesale Electricity Markets. Stanford.
- Johnstone, N., I. Haščič and M. Kalamova (2010), "Environmental Policy Design Characteristics and Technological Innovation: Evidence from Patent Data", *OECD Environment Working Papers*, No. 16, OECD Publishing, Paris, <http://dx.doi.org/10.1787/5kmjstwtqwhd-en>.
- Joskow, P.L. (1997), "Restructuring, Competition and Regulatory Reform in the U.S. Electricity Sector", *Journal of Economic Perspectives*, Vol. 11/3, pp.119-138.
- Joskow, P.L. (2008), "Lessons Learned from Electricity Market Liberalization", *The Energy Journal*, International Association for Energy Economics, Vol. 0 (Special I), pp. 9-42.
- Kalamova, M., C. Kaminker and N. Johnstone (2011), "Sources of Finance, Investment Policies and Plant Entry in the Renewable Energy Sector", *OECD Environment Working Papers*, No. 37, OECD Publishing, Paris, <http://dx.doi.org/10.1787/5kg7068011hb-en>.
- Kim E. (2013), "Deregulation and Differentiation : Incumbent investment in green technologies", *Strategic Management Journal*.

- Kitson, L., P. Wooders and T. Moerenhout (2011), “Subsidies and External Costs in Electric Power Generation: A comparative review of estimates”, IISD.
- Kopsakangas-Savolainen, M., & Svento, R. (2012). Restructuring of Electricity Markets. In *Modern Energy Markets* (pp. 5-19). Springer London.
- Kwoka, J. (2008), “Barriers to New Generation In Electricity Generation”, Report to the American Public Power Association.
- Kwoka, J. (2008), “Barriers to new competition in electricity generation”, Report to the American Public Power Association, Northeastern University.
- Masini, A. and E. Menichetti (2012), “The impact of behavioral factors in the renewable energy investment decision making process: Conceptual framework and empirical findings”, *Energy Policy*, Vol. 40, pp. 28-38.
- McAfee, Preston R., H.M. Mialon and M.A. Williams (2004), “What Is a Barrier to Entry?”, *American Economic Review*, Vol. 94/2, pp. 461-465.
- MSA (2012), *Application for Approval of a Settlement Agreement between the Market Surveillance Administrator and TransAlta Energy Marketing Corp*, Decision 2012-182, Alberta Utilities Commission, July 3, 2012.
- MSA (2015), *Market Surveillance Administrator allegations against TransAlta Corporation et al., Mr. Nathan Kaiser and Mr. Scott Connelly, Phase 1*, Decision 3110-D01-2015, Alberta Utilities Commission, July 27, 2015.
- NEA/IEA/OECD (2015), *Projected Costs of Generating Electricity 2015*, OECD Publishing, Paris, http://dx.doi.org/10.1787/cost_electricity-2015-en.
- OECD (2012), *Inventory of Estimated Budgetary Support and Tax Expenditures for Fossil Fuels 2013*, OECD Publishing, Paris, <http://dx.doi.org/10.1787/9789264187610-en>.
- OECD (2001), *Restructuring Public Utilities for Competition*, OECD Publishing, Paris, <http://dx.doi.org/10.1787/9789264193604-en>.
- Olmstead, D. E., & Ayres, M. J. (2014). Notes from a Small Market: The Energy-only Market in Alberta. *The Electricity Journal*, 27(4), 102-111.
- Papke, Leslie E. and Jeffrey M. Wooldridge (1996), “Econometric Methods for Fractional Response Variables with an Application to 401(k) Plan Participation Rates”, *Journal of Applied Econometrics*, Vol. 11/6, pp. 619–632.
- Reiss, Peter C. and Frank A. Wolak (2007), “Structural Econometric Modeling: Rationales and Examples from Industrial Organization”, in Heckman, J.J. and Leamer, E.E. (eds.), *Handbook of Econometrics (1st edition)*, Vol. 6, Elsevier.
- Rose, Kenneth (2007), “The Impact of Competition on Electricity Prices: Can We Discern a Pattern?”, Presentation to the HEPG Forty-Ninth Plenary Session.
- Saveyn, B., A. Soria Ramírez and T. Wiesenthal (2008), “Renewable electricity policy: feed-in tariffs versus tradable green certificates”, *Ekonomiaz*, Vol. 67, 1.er cuatrimestre.

- Sönmez, A. (2013), “Firm Entry, Survival, and Exit”, *Academic Journal of Interdisciplinary Studies*, Vol.2/9, MCSER Publishing, Rome.
- Tegen, S. (2006). *Comparing statewide economic impacts of new generation from wind, coal, and natural gas in Arizona, Colorado, and Michigan. National Renewable Energy Laboratory Technical Report NREL*. TP-500-37720.
- Tirole, Jean (1988), “The Theory of Industrial Organization”, 1st edition, Vol. 1/0262200716, MIT Press Books, MIT Press.

APPENDIX I. DESCRIPTIVE STATISTICS AND GRAPHS

Descriptive statistics on the main variables in the dataset are reported in Tables A1.1. – A1.3.

Table A1.1. Technology aggregates with respect to fuel type

SECTOR	Technology/subsector (fuel type)	Fuel in UDI Platts
GREEN	Biomass	BAG AGAS BGAS BIOMASS BL DGAS LGAS MANURE MBM WOOD WOODGAS WSTWSL
	Geothermal	GEO
	Hydro	WAT
	Solar	SUN
	Wind	WIND
BROWN	Coal	CGAS CKGAS COAL COG COKE CSGAS CWM PEAT
	Gas	BFG FGAS GAS GASOIL LNG LPG MGAS TGAS
	Oil	BITUMEN JET SHALE DME KERO NAP OGAS OIL ORI TSAND
	Waste	INDWST WSTCOAL HZDWST LIQ MEDWST PWST REF REFGAS RGAS RPF TIRES VOGAS WSTGAS WSTHAGAS
NUCLEAR	Nuclear	UR

Table A1.2. Descriptive statistics of the variables used for regressions

Type	Variable	Level	Obs	Mean	Std. Dev.	Min	Max
Dependent variables	Binary Entry (<i>Y_ENTRY</i>)	Country-technology	2231	.43	.50	0	1
	Capacity added by entrants in MW (<i>ENTRANTMW</i>)	Country-technology	2231	10.33	47.03	0	1061.6
	Relative Contribution rates (<i>ENTRANTMW / TOTALMW</i>)	Country-technology	1208	.431	.41	0	1
	Capacity added by all firms in MW (<i>TOTALMW</i>)	Country-technology	2231	58.87	225.21	0	4072.1
Independent variables	Herfindhal's concentration index (<i>HHI</i>)	Country-technology	2231	42.11	35.60	0	100
	Capacity penetration rates (<i>CAPPEN</i>)	Country-technology	2231	8.28	19.66	0	100
	Average vintage of units (<i>VINTAGE</i>)	Country-technology	2231	10.19	12.60	0	76.09
	Industry regulation indicator (<i>ETCR</i>)	Country	2231	3.726	1.81	0	6
	Real GDP growth (<i>GDPGROWTH</i>)	Country	2231	2.96	2.51	-11.61	11.5
	Support Policy (dummy)	Country-technology	2231	.44	.50	0	1
	Renewable Portfolio Standards (dummy)	Country-technology	2231	.18	.38	0	1
	Feed-in tariffs policy (dummy)	Country-technology	2231	.38	.49	0	1
	Renewable energy certificates policy (dummy)	Country-technology	2231	.09	.28	0	1
	FIT levels (continuous)	Country-technology	2231	3.65	9.97	0	130.5
	REC targets (continuous)	Country-technology	2231	.30	1.33	0	13
Other	Year		2231			1990	2007

Note: variables constructed from Platts UDI data, Johnstone et al. (2010) and OECD statistics.

Table A1.3. Pearson's correlation coefficients of the explanatory

	HHI	CAPPEN	VINTAGE	ETCR	GDPG	Support Policy	FIT Policy	REC Policy	FIT Levels	REC Targets
HHI	1									
CAPPEN	0.0984	1								
VINTAGE	0.2558	0.5263	1							
PMR	0.0833	0.0484	-0.1196	1						
GDPG	0.069	0.0142	-0.0181	-0.0547	1					
Support Policy	-0.091	-0.3097	-0.3094	-0.367	-0.0092	1				
FIT Policy	-0.0001	0.0012	0.0188	-0.1304	-0.0647	0.3136	1			
REC Policy	-0.0784	-0.0564	0.0976	-0.3286	-0.0131	0.1848	-0.116	1		
FIT Levels	0.008	-0.0725	-0.0835	-0.1767	-0.0015	0.2029	0.4665	-0.0807	1	
REC Targets	-0.089	-0.0222	0.1122	-0.2307	0.0084	0.1526	-0.0265	0.7369	-0.0643	1

Figure A1.1. is composed of four descriptive graphs. The top graphs show average feed-in tariffs in US cent/kWh and renewable energy certificates in terms of targets are plotted for all technologies and countries against the value of the aggregated regulatory indicator. The bottom graphs draw counts of policies in force and regulatory indicators for all countries are plotted across time and then smoothed using a 5th order polynomial in order to show the general dynamics of both policy and regulation in OECD countries over the period. A similar graph is drawn for FIT and REC.

Figure A1.1. Renewable Policies and Industry Regulation

Note: Polynomial time trends are based on all values of the variable of interest across countries and technologies.

Figure A1.1. is composed of four descriptive graphs. The top graphs show average feed-in tariffs in US cent/kWh and renewable energy certificates in terms of targets are plotted for all technologies and countries against the value of the aggregated regulatory indicator. The bottom graphs draw counts of policies in force and regulatory indicators for all countries are plotted across time and then smoothed using a 5th order polynomial in order to show the general dynamics of both policy and regulation in OECD countries over the period. A similar graph is drawn for FIT and REC.

Figure A1.2. Green and Brown Capacity installed by entrants and incumbents

Note: Polynomial time trends are based on all values of the variable of interest across countries and technologies.

Figure A1.2. draws polynomial time trends of annual renewable capacity additions in OECD countries by entrants and incumbents. They can be seen as the graphs of the average capacity of green and brown technologies installed by type of firms in a developed country along time. Countries with large annual capacity additions are obviously very influential on the average values although we are interested by the patterns of capacity additions. Brown capacity additions exhibit a very important boom and bust pattern, mostly due to the large investment boom in gas-fired power plants around year 2000, whereas renewable capacity additions appear subject to less fluctuation, in particular those of entrants.

Figure A1.3. Kernel Density Plots of Plant Entry Sizes by Firm Types (<75th percentile)

Note: Epanechnikov Kernel functions. Values above the 75th percentile are not drawn. Figure A1.3. shows six kernel density plots of plant entry sizes by firm types for selected technologies. They provide a better view of which type of firms, i.e. new entrants, diversifying incumbents (incumbent-entrants), and incumbents, invests in larger or smaller plants than the others.

Figure A1.4. Concentration indices and regulation indicators

Note: The above figure depicts a 3rd order polynomial smoothing of the relationship between the regulation indicator and concentration measures, pooled across countries and years. High ETCR values should typically be associated with high HHI values, since part of the ETCR is based on questions measuring industry concentration.

Figure A1.4 plots the country concentration index (HHI) against the regulation indicator for all sampled countries and years, along with a 3rd order polynomial smoothing. We find low values of the regulation indicator to be consistently associated with low concentration measures, whereas larger ETCR values are associated with much dispersed HHI values, although larger on average. This could be due to measurement errors from the limited data on plants' ownership.

APPENDIX II: RESULTS TABLES

Table A2.1. Exponentiated coefficients of the logistic regressions (M1)

Dependent variable : Binary variable coded 1 if entry is observed, 0 otherwise (logit)						
Variables	(1)	(2) no hydro or geothermal	(3)	(4) no hydro or geothermal	(5)	(6) no hydro or geothermal
HHI	0.9978 (0.332)	0.9950 [*] (0.085)	0.9976 (0.279)	0.9946 ^{**} (0.050)	0.9977 (0.324)	0.9947 [*] (0.069)
CAPPEN	1.0429 ^{***} (0.000)	1.0165 (0.896)	1.0431 ^{***} (0.000)	1.0387 (0.735)	1.0433 ^{***} (0.000)	1.0406 (0.744)
VINTAGE	1.0137 (0.407)	1.0603 ^{**} (0.011)	1.0106 (0.536)	1.0616 ^{**} (0.010)	1.0113 (0.513)	1.0567 ^{**} (0.022)
ETCR Regulation	0.8442 ^{***} (0.002)	0.7859 ^{***} (0.004)	0.8158 ^{***} (0.001)	0.8036 ^{***} (0.009)	0.7983 ^{***} (0.000)	0.7695 ^{***} (0.001)
Real GDP growth	0.9805 (0.390)	0.9689 (0.288)	0.9843 (0.474)	0.9686 (0.271)	0.9914 (0.698)	0.9792 (0.474)
RENPOL:						
Support Policy (dummy)	2.2261 ^{***} (0.000)	1.7980 ^{**} (0.016)	-	-	-	-
FIT (dummy)	-	-	2.2901 ^{***} (0.001)	3.2783 ^{***} (0.001)	-	-
REC (dummy)	-	-	1.2104 (0.475)	1.8547 ^{**} (0.035)	-	-
Feed-in tariff levels (continuous)	-	-	-	-	1.0281 ^{***} (0.006)	1.0302 ^{***} (0.009)
REC targets (continuous)	-	-	-	-	0.9912 (0.794)	1.0470 (0.203)
Geothermal (dummy)	0.0169 ^{***} (0.000)	-	0.0171 ^{***} (0.000)	-	0.0183 ^{***} (0.000)	-
Hydro (dummy)	0.4911 (0.119)	-	0.3482 ^{**} (0.028)	-	0.3409 ^{**} (0.025)	-
Solar (dummy)	0.2477 ^{***} (0.000)	0.2663 ^{***} (0.000)	0.2504 ^{***} (0.000)	0.2623 ^{***} (0.000)	0.2145 ^{***} (0.000)	0.2214 ^{***} (0.000)
Wind (dummy)	2.6146 ^{***} (0.000)	3.2170 ^{***} (0.000)	2.5313 ^{***} (0.000)	3.2397 ^{***} (0.000)	2.4147 ^{***} (0.000)	2.9696 ^{***} (0.000)
Country fixed-effects	YES	YES	YES	YES	YES	YES
Subsector fixed-effects	YES	YES	YES	YES	YES	YES
Pseudo R^2	0.329	0.321	0.328	0.331	0.327	0.325
N	2231	1464	2231	1464	2231	1464

Exponentiated coefficients; p -values in parentheses, based on cluster-robust standard errors. The cluster variable is country-subsector. ^{*} $p < 0.10$, ^{**} $p < 0.05$, ^{***} $p < 0.01$

1. Models (1), (3) and (4) include observations for the five renewable energy subsectors while (2), (4), and (6) exclude all observations for the hydro and geothermal subsectors which are more mature, more capital-intensive and hence may exhibit different characteristics than other renewables. Models (1) and (2) consider a single policy dummy for the presence of renewable support policies. (3) and (4) include binary variables for feed-in-tariff and renewable energy certificate policies. Finally (5) and (6) include FIT levels in US cents/kwh and REC levels in percentage points. Other policy dummies were not used to avoid collinearity problems.

Table A2.2. Estimated coefficients of the semi-log linear model (M2)

Dependent variable: log renewable capacity additions of entrants in MW (semi-log OLS)						
Variables	(1)	(2) no hydro or geothermal	(3)	(4) no hydro or geothermal	(5)	(6) no hydro or geothermal
HHI	-0.0055 [*] (0.076)	-0.0064 [*] (0.059)	-0.0062 ^{**} (0.050)	-0.0067 ^{**} (0.040)	-0.0052 (0.112)	-0.0059 [*] (0.086)
CAPPEN	0.0192 ^{***} (0.006)	0.1112 ^{**} (0.021)	0.0173 ^{**} (0.023)	0.1250 ^{***} (0.006)	0.0177 ^{**} (0.018)	0.1406 ^{***} (0.004)
VINTAGE	0.0160 (0.365)	0.0535 ^{**} (0.012)	0.0097 (0.607)	0.0436 ^{**} (0.040)	0.0138 (0.482)	0.0501 ^{**} (0.021)
ETCR Regulation	-0.1905 ^{***} (0.008)	-0.3387 ^{***} (0.001)	-0.1882 ^{**} (0.011)	-0.2819 ^{***} (0.003)	-0.2202 ^{***} (0.003)	-0.3073 ^{***} (0.002)
Real GDP growth	-0.0108 (0.749)	0.0392 (0.406)	0.0017 (0.961)	0.0264 (0.542)	0.0182 (0.641)	0.0589 (0.257)
RENPOL:						
Support Policy (dummy)	0.8322 ^{***} (0.001)	0.4757 [*] (0.093)				
FIT (dummy)			0.4618 ^{**} (0.040)	0.7182 ^{**} (0.011)		
REC (dummy)			0.8191 ^{**} (0.033)	1.1136 ^{***} (0.009)		
Feed-in tariff levels (continuous)					0.0201 [*] (0.088)	0.0290 ^{***} (0.006)
REC targets (continuous)					0.0713 (0.290)	0.1120 (0.230)
Geothermal (dummy)	0.2234 (0.806)		0.1734 (0.837)		0.2228 (0.786)	
Hydro (dummy)	-1.1473 ^{**} (0.044)		-1.3818 ^{**} (0.018)		-1.4424 ^{**} (0.014)	
Solar (dummy)	-3.1083 ^{***} (0.000)	-2.8139 ^{***} (0.000)	-3.0499 ^{***} (0.000)	-2.8594 ^{***} (0.000)	-3.2147 ^{***} (0.000)	-3.0944 ^{***} (0.000)
Wind (dummy)	0.8647 ^{***} (0.001)	1.0238 ^{***} (0.000)	0.8350 ^{***} (0.002)	0.9245 ^{***} (0.001)	0.8646 ^{***} (0.002)	0.9485 ^{***} (0.001)
Country fixed-effects	YES	YES	YES	YES	YES	YES
Subsector fixed-effects	YES	YES	YES	YES	YES	YES
adj. R^2	0.530	0.611	0.525	0.624	0.522	0.620
N	951	656	951	656	951	656

p -values in parentheses, based on cluster-robust standard errors. The cluster variable is country-subsector. ^{*} $p < 0.10$, ^{**} $p < 0.05$, ^{***} $p < 0.01$

Table A2.3 Estimated coefficients of the semi-log linear model (all firms, M3)

Dependent variable : log capacity additions in MW (OLS)						
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Concentration (HHI)	-0.0084** (0.035)	-0.0071* (0.082)	-0.0088** (0.029)	-0.0075* (0.066)	-0.0079* (0.056)	-0.0069 (0.109)
CAPPEN	0.0334*** (0.000)	0.2551*** (0.000)	0.0309*** (0.001)	0.2717*** (0.000)	0.0313*** (0.001)	0.2822*** (0.000)
Vintage	-0.0081 (0.695)	0.0407* (0.078)	-0.0142 (0.536)	0.0351 (0.145)	-0.0058 (0.796)	0.0461** (0.049)
ETCR Regulation	-0.0752 (0.364)	-0.2685** (0.021)	-0.0939 (0.292)	-0.2556** (0.030)	-0.1250 (0.157)	-0.2884** (0.016)
Real GDP growth	0.0382 (0.321)	0.0877 (0.121)	0.0606 (0.130)	0.0912* (0.090)	0.0757* (0.091)	0.1263* (0.052)
RENPOL:						
Support Policy (dummy)	1.0951*** (0.000)	0.7968** (0.015)				
FIT (dummy)			0.4843** (0.046)	0.6978** (0.022)		
REC (dummy)			0.8127* (0.058)	1.1768** (0.015)		
Feed-in tariff levels (continuous)					0.0218* (0.054)	0.0246** (0.018)
REC targets (continuous)					0.0598 (0.370)	0.0873 (0.324)
Geothermal (dummy)	1.0352* (0.071)		1.1041* (0.054)		1.0339* (0.062)	
Hydro (dummy)	0.9880 (0.171)		0.6327 (0.396)		0.5045 (0.491)	
Solar (dummy)	-3.2796*** (0.000)	-2.9027*** (0.000)	-3.1757*** (0.000)	-2.9123*** (0.000)	-3.2909*** (0.000)	-3.0275*** (0.000)
Wind (dummy)	1.1531*** (0.000)	1.3832*** (0.000)	1.1468*** (0.000)	1.3140*** (0.000)	1.2240*** (0.000)	1.3984*** (0.000)
Country fixed-effects	YES	YES	YES	YES	YES	YES
Subsector fixed-effects	YES	YES	YES	YES	YES	YES
adj. R^2	0.692	0.722	0.684	0.726	0.682	0.720
N	1208	750	1208	750	1208	750

p-values in parentheses, based on cluster-robust standard errors. The cluster variable is country-subsector. * p < 0.10, ** p < 0.05, *** p < 0.01

Table A2.4 Estimated coefficients of the semi-log linear model (micro-level, M4)

Dependent variable : log capacity additions (OLS)						
Variables	(1)	(2)	(3)	(4)	(5)	(6)
HHI	-0.0092*** (0.000)	-0.0088*** (0.002)	-0.0091*** (0.000)	-0.0092*** (0.001)	-0.0073*** (0.003)	-0.0073*** (0.009)
CAPPEN	0.0137*** (0.003)	0.0577*** (0.003)	0.0141*** (0.003)	0.0546*** (0.005)	0.0459*** (0.002)	0.0792*** (0.000)
VINTAGE	-0.0420*** (0.000)	-0.0302** (0.045)	-0.0465*** (0.000)	-0.0286* (0.052)	-0.0468*** (0.000)	-0.0300** (0.043)
ETCR Regulation	-0.2101*** (0.000)	-0.4107*** (0.000)	-0.2558*** (0.000)	-0.4356*** (0.000)	-0.2570*** (0.000)	-0.4243*** (0.000)
Real GDP growth	-0.0137 (0.442)	-0.0011 (0.962)	-0.0195 (0.282)	-0.0011 (0.963)	-0.0167 (0.352)	0.0020 (0.932)
RENPOL:						
Support Policy (dummy)	0.4847*** (0.000)	0.3220*** (0.009)				
RPS Policy (dummy)	0.1936* (0.054)	0.0584 (0.618)				
FIT (dummy)			0.5089*** (0.000)	0.5488*** (0.000)		
REC (dummy)			-0.0302 (0.809)	-0.0398 (0.785)		
Feed-in tariff levels (continuous)					0.0232*** (0.000)	0.0217*** (0.000)
REC targets (continuous)					0.0673*** (0.001)	0.0594*** (0.010)
Utility (dummy)	0.0058 (0.958)	-0.2962** (0.020)	0.0336 (0.761)	-0.2748** (0.031)	0.0405 (0.715)	-0.2558** (0.046)
Size (dummy)	1.0743*** (0.000)	0.7526*** (0.000)	1.0779*** (0.000)	0.7459*** (0.000)	1.0886*** (0.000)	0.7460*** (0.000)
Entrant (dummy)	-0.4858*** (0.000)	-0.4173*** (0.001)	-0.5012*** (0.000)	-0.4246*** (0.000)	-0.5102*** (0.000)	-0.4349*** (0.000)
Greenshare (firm-level)	0.0071*** (0.000)	0.0045*** (0.008)	0.0071*** (0.000)	0.0044*** (0.010)	0.0072*** (0.000)	0.0044*** (0.010)
Greenshare (country-level)	0.0483*** (0.001)	-0.0014 (0.943)	0.0495*** (0.001)	-0.0016 (0.934)	0.0457*** (0.001)	-0.0182 (0.344)
Market Share (continuous)	0.0172*** (0.000)	0.0074* (0.055)	0.0173*** (0.000)	0.0074* (0.055)	0.0170*** (0.000)	0.0073* (0.058)
Portfolio Concentration (index 0-100)	-0.0027 (0.331)	-0.0074** (0.016)	-0.0022 (0.417)	-0.0073** (0.018)	-0.0024 (0.394)	-0.0073** (0.018)
Geothermal (dummy)	1.2429*** (0.000)		1.2050*** (0.000)		1.1541*** (0.000)	
Hydro (dummy)	0.7300** (0.019)		0.4821 (0.124)		0.4775 (0.122)	
Solar (dummy)	-2.9997*** (0.000)	-2.7887*** (0.000)	-2.9967*** (0.000)	-2.7805*** (0.000)	-3.4033*** (0.000)	-3.1362*** (0.000)
Wind (dummy)	0.0131 (0.924)	0.1521 (0.356)	0.0036 (0.979)	0.1662 (0.301)	0.0193 (0.888)	0.1397 (0.391)
Constant	0.1494 (0.760)	2.3994*** (0.000)	0.5514 (0.274)	2.6768*** (0.000)	0.5006 (0.294)	2.8372*** (0.000)
Country fixed-effects	YES	YES	YES	YES	YES	YES
Subsector fixed-effects	YES	YES	YES	YES	YES	YES
adj. R^2	0.400	0.481	0.399	0.483	0.403	0.486
N	4425	2858	4425	2858	4425	2858

p-values in parentheses, based on cluster-robust standard errors. The cluster variable is country-subsector. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A2.5 Estimated coefficients of the linear model (M5)

Dependent variable : Capacity additions of entrants relative to total capacity additions (%) (OLS)						
Variables	(1)	(2)	(3)	(4)	(5)	(6)
HHI	0.0018*** (0.009)	0.0016** (0.041)	0.0018*** (0.008)	0.0016** (0.033)	0.0005 (0.424)	0.0016** (0.033)
CAPPEN	-0.0024* (0.060)	-0.0219*** (0.008)	-0.0025** (0.046)	-0.0211** (0.018)	-0.0029** (0.023)	-0.0188** (0.029)
VINTAGE	0.0110*** (0.000)	0.0102** (0.013)	0.0096*** (0.002)	0.0097** (0.022)	0.0095*** (0.004)	0.0104** (0.025)
ETCR Regulation	0.0295** (0.018)	0.0391** (0.015)	0.0355*** (0.005)	0.0438*** (0.009)	0.0429*** (0.001)	0.0420** (0.011)
Real GDP growth	0.0105** (0.049)	0.0109 (0.160)	0.0097* (0.090)	0.0096 (0.241)	0.0119** (0.035)	0.0131 (0.116)
RENPOL						
Support Policy (dummy)	0.0380 (0.359)	0.0602 (0.191)	-	-	-	-
FIT (dummy)	-	-	0.1055*** (0.006)	0.1350** (0.015)	-	-
REC (dummy)	-	-	0.0621* (0.092)	0.0753* (0.099)	-	-
Feed-in tariff levels (continuous)	-	-	-	-	0.0016 (0.152)	0.0039*** (0.001)
REC targets (continuous)	-	-	-	-	0.0096 (0.144)	0.0106 (0.227)
Geothermal (dummy)	-0.5142*** (0.000)	-	-0.5115*** (0.000)	-	-0.4265*** (0.000)	-
Hydro (dummy)	-0.4696*** (0.000)	-	-0.4576*** (0.000)	-	-0.4508*** (0.000)	-
Solar (dummy)	0.1793** (0.027)	0.1605** (0.047)	0.1716** (0.031)	0.1557* (0.054)	0.2207*** (0.006)	0.1262 (0.161)
Wind (dummy)	-0.0368 (0.428)	-0.0529 (0.260)	-0.0481 (0.308)	-0.0581 (0.237)	-0.0604 (0.209)	-0.0549 (0.282)
Country fixed-effects	YES	YES	YES	YES	YES	YES
Subsector fixed-effects	YES	YES	YES	YES	YES	YES
adj. R^2	0.615	0.701	0.617	0.703	0.623	0.703
N	1167	712	1167	712	1208	712

p-values in parentheses, based on cluster-robust standard errors. The cluster variable is country-subsector. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Interactions of policies and regulation in model (M1) to (M4)

Table A2.6 shows the results of the estimation of model (M1) (M2) (M3) and (M4). Columns (2) (4) (6) and (8) present results when models are estimated with a smaller sample that excludes hydro and geothermal power installations. All the interactions are between a dummy for regulation, equal to 1 for values of the aggregate PMR for the electricity industry above 2, and continuous policy variables such as FIT levels and REC targets. No insightful results are found. Findings are briefly described in Section 4 (model (M1) and (M2)).

Table A2.6. Estimated coefficients of model (M1) to (M4) with interacted variables

(#) [Model] Dependent variable :		(1-2) [Logit] Binary entry; (3-4) [OLS] Log MW added of entrants; (5-6) [OLS] Log MW added of all firms; (7-8) [OLS] Log MW added at the firm level						
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HHI	-0.0021 (0.372) ^{***}	-0.0047 (0.116)	-0.0090 ^{***} (0.005)	-0.0101 ^{***} (0.002)	-0.0121 ^{***} (0.001)	-0.0125 ^{***} (0.000)	-0.0085 ^{***} (0.000)	-0.0100 ^{***} (0.000)
CAPPEN	0.0419 (0.000)	0.0950 (0.476) ^{**}	0.0188 ^{***} (0.009)	0.1710 ^{***} (0.000)	0.0324 ^{***} (0.000)	0.2932 ^{***} (0.000)	1.4060 ^{***} (0.003)	8.8080 ^{***} (0.000)
VINTAGE	0.0162 (0.345)	0.0555 ^{**} (0.025)	0.0062 (0.730)	0.0293 (0.142)	-0.0245 (0.268)	0.0159 (0.473)	-0.0340 ^{***} (0.001)	-0.0232 (0.121)
Real GDP growth	0.0081 (0.716)	-0.0007 (0.981)	-0.0206 (0.512)	0.0111 (0.794)	0.0112 (0.727)	0.0347 (0.368)	-0.0025 (0.888)	0.0161 (0.501)
ETCR Regulation (dummy)	-0.5276 ^{**} (0.031)	-0.5946 [*] (0.076)	-0.6404 ^{***} (0.009)	-0.8619 ^{***} (0.005)	-0.7275 ^{**} (0.011)	-1.0610 ^{***} (0.002)	-0.7806 ^{***} (0.000)	-1.1786 ^{***} (0.000)
RENPOL and interactions:								
FIT levels	0.0232 [*] (0.056)	0.0240 [*] (0.096)	0.0316 [*] (0.057)	0.0306 [*] (0.057)	0.0320 ^{**} (0.041)	0.0271 [*] (0.081)	0.0285 ^{***} (0.000)	0.0232 ^{***} (0.001)
ETCR_D * FIT	0.0264 (0.069)	0.0301 [*] (0.067) ^{**}	-0.0162 (0.386)	0.0072 (0.674) ^{**}	-0.0177 (0.314)	0.0019 (0.915)	-0.0141 [*] (0.072)	0.0019 (0.851)
REC targets	0.0986 (0.090)	0.1579 ^{**} (0.034)	0.1440 (0.122)	0.2047 ^{**} (0.044)	0.0796 (0.410)	0.1279 (0.280)	0.0562 [*] (0.067)	0.0370 (0.245)
ETCR*_D*REC	-0.0941 (0.157) ^{***}	-0.0886 (0.279)	-0.0804 (0.339)	-0.0882 (0.439)	-0.0405 (0.655)	-0.0388 (0.756)	0.0371 (0.299)	0.0681 [*] (0.068)
Geothermal (dummy)	-3.9729 ^{***} (0.000)	-	-0.0383 (0.965)	-	0.9249 (0.114)	-	1.0735 ^{***} (0.000)	-
Hydro (dummy)	-1.1650 ^{**} (0.014)	-	-1.5203 ^{***} (0.007)	-	0.5547 (0.436)	-	0.1720 (0.562)	-
Solar (dummy)	-1.5102 ^{***} (0.000)	-1.4494 ^{***} (0.000)	-3.4944 ^{***} (0.000)	-3.2580 ^{***} (0.000)	-3.7276 ^{***} (0.000)	-3.3159 ^{***} (0.000)	-3.3648 ^{***} (0.000)	-2.9813 ^{***} (0.000)
Wind (dummy)	0.8722 ^{***} (0.000)	1.0542 ^{***} (0.000)	0.5916 ^{**} (0.023)	0.6139 ^{**} (0.012)	0.7826 ^{***} (0.008)	0.9335 ^{***} (0.000)	0.1164 (0.397)	0.1828 (0.263)
UTILITY (dummy)	-	-	-	-	-	-	0.0373 (0.736)	-0.2391 [*] (0.061)
SIZE (dummy)	-	-	-	-	-	-	1.0916 ^{***} (0.000)	0.7498 ^{***} (0.000)
ENTRANT (dummy)	-	-	-	-	-	-	-0.5256 ^{***} (0.000)	-0.4649 ^{***} (0.000)
GREENSHA RE (firm-level)	-	-	-	-	-	-	0.6634 ^{***} (0.000)	0.3580 ^{**} (0.035)
GREENSHA RE (country-level)	-	-	-	-	-	-	4.8733 ^{***} (0.000)	1.0399 (0.581)
MARKETSHARE	-	-	-	-	-	-	0.0159 ^{***} (0.000)	0.0055 (0.151)
PORTFOLIO CONC	-	-	-	-	-	-	-0.0024 (0.380)	-0.0069 ^{**} (0.027)
Constant	0.1879 (0.657)	0.1669 (0.784)	1.8684 ^{***} (0.000)	1.7701 ^{***} (0.000)	2.5007 ^{***} (0.000)	2.4454 ^{***} (0.000)	0.1433 (0.758)	1.8364 ^{***} (0.001)
Country fixed-effects	YES	YES	YES	YES	YES	YES	YES	YES
Subsector fixed-effects	YES	YES	YES	YES	YES	YES	YES	YES
Adj./Ps. R ²	0.321	0.318	0.409	0.501	0.445	0.577	0.404	0.481
N	2231	1464	951	656	1208	750	4425	2858

Exponentiated coefficients; *p*-values in parentheses, based on cluster-robust standard errors. The cluster variable is country-subsector. * *p* < 0.10, ** *p* < 0.05, *** *p* < 0.01

Additional descriptive figures related to model (M4)

Figures A2.1. to A2.4 provide additional information upon the relationship between the size of firms, portfolio concentration and the share of renewable capacity. The discussion in Section 5 following the results of model (M4) refers to those figures.

Figure A2.1. Portfolio concentration and firms' size

Figure A2.2. Shares of green capacity and firms' size

Figure A2.3. Small firms: Portfolio and Renewables **Figure A2.4. Large firms: Portfolio and Renewables**

Interactions of policies and regulation in model (M5)

Table A1.5 shows the results of the estimation of model (M5) with the dependent based on numbers of installations in columns (1) to (4) and on capacity additions in MW in columns (5) to (8). Also, columns (2) (4) (6) and (8) present results when models are estimated with a smaller sample that excludes hydro and geothermal power installations. Finally, the interaction in columns (1) (2) (5) and (6) are between a dummy for regulation and continuous variables whereas those in (3) (4) (7) and (8) are between binary policy variables and the continuous indicators for regulation.

Table A2.7. Estimated coefficients of model (M5) with interacted variables

(#) [Model] Dependent variable:		(1-4) [OLS] Relative contribution of entrants to number of plants added (%);		(5-8) [OLS] Relative contribution of entrants to capacity added (%);					
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
HHI	0.0017*** (0.008)	0.0017** (0.019)	0.0014** (0.040)	0.0010 (0.193)	0.0021*** (0.002)	0.0021*** (0.004)	0.0017** (0.012)	0.0015* (0.056)	
CAPPEN	-0.0016 (0.169)	-0.0208** (0.023)	-0.0017 (0.139)	-0.0197** (0.031)	-0.0023* (0.059)	-0.0238*** (0.007)	-0.0025** (0.047)	-0.0245*** (0.007)	
VINTAG	0.0095*** (0.004)	0.0080* (0.093)	0.0084*** (0.007)	0.0055 (0.158)	0.0105*** (0.001)	0.0114** (0.018)	0.0093*** (0.003)	0.0096** (0.020)	
E									
Real GDP growth	0.0134** (0.017)	0.0141* (0.072)	0.0124** (0.023)	0.0106 (0.169)	0.0109* (0.058)	0.0127 (0.122)	0.0101* (0.078)	0.0096 (0.254)	
Regulation (dummy)	0.1167** (0.020)	0.1016* (0.092)	-	-	0.1305*** (0.007)	0.0991* (0.085)	-	-	
Feed-in tariff levels	0.0030* (0.075)	0.0023 (0.135)	-	-	0.0052*** (0.002)	0.0039*** (0.006)	-	-	
Reg=1#	-0.0033 (0.127)	-0.0006 (0.805)	-	-	-0.0056*** (0.010)	-0.0013 (0.549)	-	-	
FIT levels									
REC targets	0.0232 (0.176)	0.0341 (0.122)	-	-	0.0238 (0.184)	0.0351* (0.060)	-	-	
Reg=1# REC targets	-0.0324* (0.066)	-0.0424* (0.073)	-	-	-0.0288 (0.114)	-0.0421** (0.028)	-	-	
Electricity (indicator)	-	-	0.0618*** (0.000)	0.0770*** (0.000)	-	-	0.0613*** (0.000)	0.0683*** (0.004)	
FIT Policy	-	-	0.2700*** (0.002)	0.2927*** (0.007)	-	-	0.3001*** (0.001)	0.3132*** (0.004)	
FITPolicy =1 #	-	-	-0.0502*** (0.010)	-0.0547** (0.029)	-	-	-0.0541*** (0.007)	-0.0523** (0.047)	
Electricity REC Policy	-	-	0.0975 (0.361)	0.1422 (0.306)	-	-	0.0540 (0.585)	0.1165 (0.249)	
RECPolicy =1 #	-	-	-0.0150 (0.776)	-0.0251 (0.728)	-	-	0.0057 (0.908)	0.0253 (0.636)	
Electricity Geothermal (dummy)	-0.5172*** (0.000)	-	-0.5252*** (0.000)	-	-0.5166*** (0.000)	-	-0.5224*** (0.000)	-	
Hydro (dummy)	-0.3726*** (0.001)	-	-0.3641*** (0.001)	-	-0.4759*** (0.000)	-	-0.4635*** (0.000)	-	
Solar (dummy)	0.1578* (0.061)	0.1282 (0.147)	0.1693** (0.025)	0.1498* (0.056)	0.1287 (0.146)	0.1084 (0.228)	0.1590** (0.040)	0.1459* (0.063)	
Wind (dummy)	0.0080 (0.876)	-0.0170 (0.770)	-0.0207 (0.647)	-0.0549 (0.248)	-0.0327 (0.506)	-0.0355 (0.507)	-0.0598 (0.171)	-0.0637 (0.162)	
Country fixed-effects	YES	YES	YES	YES	YES	YES	YES	YES	
Subsector fixed-effects	YES	YES	YES	YES	YES	YES	YES	YES	
adj. R ²	0.695	0.756	0.701	0.764	0.616	0.700	0.621	0.706	
N	1167	712	1167	712	1167	712	1167	712	

Exponentiated coefficients; *p*-values in parentheses, based on cluster-robust standard errors. The cluster variable is country-subsector. * *p* < 0.10, ** *p* < 0.05, *** *p* < 0.01

Validation of the regression models

This section presents residual plots and post-estimation results for model (M1) (M2) (M4) and (M5) that seek to provide some validation of the regression models presented in the report. For consistency we only report post-estimation statistics for the models including all renewable subsectors and the dummy for policy support as regressors, that is column (1) in the respective regression tables, although results would not be changed otherwise.

Model (M1) – Logistic Regression

Figure A2.5 is the Receiver Operating Characteristic (ROC) curve, it plots the true positive rate against the false positive rate. The area under the curve here is 0.86, which is evidence of a good accuracy of the model.

Figure A2.5. ROC curve (M1)

The frequency of ‘success’ ($Y_{Entry}=1$) in the estimation sample is 42.63% while the sensitivity (true positive rate) of the model is 72.87%, i.e. the ability of the model to correctly predict ‘success’, and the specificity (true negative rate) equals 84.53%. Finally, the rate of correctly specified values is 79.56%. Overall, the model has a fairly satisfactory predictive power.

Model (M2) – Semi-log OLS Regression

Figures A2.6 to A2.9 present residuals plots. It appears that some serial correlation remains (Fig. A1.12.), although it does not seem worrying. Apart from this, residuals are ‘well-behaved’ speaking in favour of the model specification:

- No patterns between residuals and fitted values
- Residuals are normally distributed
- There is a positive correlation, though not dramatic, between lagged residuals and residuals but clustered residuals are used to account for this.
- No discernible pattern between residuals and the order of data.

Figure A2.6. Fitted values vs. residuals

Figure A2.7. Residuals vs. normal probability scale

Figure A2.8. Residuals vs. lagged residuals

Figure A2.9. Residuals vs. observation sequence

Model (M4) – Semi-log OLS regression with micro-level data

Figures A2.10 to A2.13 present residual plots. The same conclusions arise:

- No patterns between residuals and fitted values
- Residuals are normally distributed
- There is a positive correlation, though not dramatic, between lagged residuals and residuals but clustered residuals are used to account for this.
- No discernible pattern between residuals and the order of data.

Figure A2.10. Fitted values vs. residuals

Figure A2.11. Residuals vs. normal probability scale

Figure A2.12. Residuals vs. lagged residuals

Figure A2.13. Residuals vs. observation sequence

Model (M5) – OLS Regression with a proportion as a dependent variable

Figures A2.14 to A2.17 present residual plots. The same conclusions arise:

- No patterns between residuals and fitted values (the peculiar form of the scatterplot comes from the limited nature of the dependent variable)
- Residuals are normally distributed
- There is a positive correlation, though not dramatic, between lagged residuals and residuals but clustered residuals are used to account for this.
- No discernible pattern between residuals and the order of data.

Figure A2.14. Fitted values vs. residuals

Figure A2.15. Residuals vs. normal probability scale

Figure A2.16. Residuals vs. lagged residuals

Figure A2.17. Residuals vs. observation sequence