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# Something's in the Air:

## Exploring Wind Power Investment Incentives in Sweden

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**Abstract:** Swedish wind power generation levels have shifted materially over the last decade, nearly accounting for 20% of the total electricity supply by the end of 2021. Along with rapid infrastructure development, industry ownership structures have changed, and foreign equity in wind power is estimated to increase from 36% in 2016 to 66% in 2024. As wind power production is associated with reduced electricity prices, incumbents may be less motivated to invest than domestic and foreign entrants due to price cannibalization effects on existing output. To determine if such incentive dynamics can explain the investment patterns of firms, we estimate the price effect through a regression analysis and develop a marginal profitability model with two bidding areas. The results show that during 2018-2021, a 1% increase in Swedish wind power was associated with 0.05-0.19% lower wholesale electricity prices. A short-run analysis finds that entrants, particularly foreign firms, are more inclined to expand wind power, and sufficiently large incumbents are distinctly disincentivized to do so. However, data reveals that incumbents still expand. Using a long-run equilibrium analysis with strategic decision-making of potential deterrence, we outline the conditions that could justify such development. These conclusions have several implications relating to both production prediction and foreign policy, and extend the existing literature on intra-regional electricity price effects related to renewable production in Sweden.

**Keywords:** Wind Power, Merit Order Effect, Swedish Electricity Market, Firm Profitability, Investments

**JEL:** D22, L13, Q42

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# Contents

# 1 Introduction

Renewable energy (RE) production is one of the critical solutions to counter global climate change. Recent technological improvements have made RE generation increasingly price-competitive while also being an inexhaustible energy source associated with improved air quality. As a result, the worldwide adoption of renewable energy has surged in recent decades.

The expanded use of renewables in Europe was formalized in 2009 with the Renewable Energy Directive, declaring that 32% of total energy consumption in the EU should stem from renewable sources by 2030, with a provisional agreement to increase the target to 42.5% (European Commission, 2023). In addition to the overarching objective, each country set an individual RE target. With its vast hydropower resources, Sweden surpassed its goal of 50% renewables in the energy mix by 2020 and targets 100% renewables by 2040 (Swedish Parliament, 2018).

Many nations, including the Nordic countries, rely on wind power expansion to achieve their targets. With the significant growth of wind power investment, ownership trends and structures are also transforming. In Sweden, foreign ownership of wind power is expected to increase from 36% to 66% during the eight years from 2016 to 2024 (SWEA, 2022). This structural change of ownership has raised concerns. A Swedish government commission has proposed that certain infrastructure investments be subject to reviews before they can be commenced. Questions on national security have been raised in the Swedish parliament, not the least because the largest wind power owner in Sweden is the Chinese state-owned firm CGN (SOU, 2021; Swedish Parliament, 2021, 2022, 2022).

Regardless of ownership, the negative impact of renewable energy on electricity prices has been observed for various geographical markets using various estimation methods (Gil et al., 2012; Macedo et al., 2021, among others). Known as the merit order effect, it is one of the most established effects of renewable energy. Contrary to conventional power generation, renewable energy requires no input goods and thus carries a negligible or very low marginal cost. Under the marginal price-setting regime of the Walrasian auction in the Nordic electricity exchange Nord Pool, the low-cost RE will enter the supply merit order at the outset. Consequently, it will be the first energy source to be deployed in the system, replacing costlier conventional power production. As a result, auction prices will clear at lower levels.

The merit order effect could impact incumbent firms, which may face lower revenues on their current electricity generation. Accordingly, the firms with the highest market shares should be subject to the most considerable relative losses from expanded RE generation. We aim to shed light on the emergence of foreign wind power ownership and its possible relation to incumbent firms' diminishing investment incentives due to lowered electricity prices.

We study the Swedish electricity market from January 1, 2018, to December 31, 2021. Our empirical results show that a 1% increase in wind power production is associated with a decrease of, on average, 0.05-0.19% in wholesale electricity prices, depending on the region. The results point to diminishing short-run incentives for incumbent firms looking to invest in wind power. When allowing for potential differences in entry and capital costs across domestic and foreign firms – among other factors – we also find conditions that would allow foreign entrants to dominate the market. However, large incumbents still invest in wind power. Under the assumption that incumbent firms can influence the decisions of potential entrants through their actions in the long run, investing can be a dominant strategy even if short-term losses are predicted.

This paper relates to the wide range of literature on foreign direct investments (FDI) and the more narrow subset on renewable energy FDI. Foreign direct investments are associated with positive host-country effects through technology transfer and adaptation (Batten and Vo, 2009). In a study on the determinants of FDI in renewable energy generation during the early 2000s, Hanni et al. (2011) find that most investments during the decade were carried out in Europe, largely because of the RE target commitments. The investments were primarily commenced due to saturated home markets, first-mover advantages to exploit accumulated experience, and emerging opportunities abroad in terms of government incentives. These factors constitute a foundation for understanding the growth of foreign ownership in Swedish RE generation. Furthermore, LV and Spigarelli (2016) study the locational choices of Chinese FDI in the European renewable energy sector. They find that Chinese firms value host countries with large market sizes, high market affluence, stable political environments, and low trade barriers, which can contribute to explaining the influx of Chinese renewable energy FDI in Sweden.

Our results are coherent with other research regarding the short-term merit order effect. Even though the short-term merit order effect is considered valid in many settings, the long-term effect is not as clear-cut, which could limit the degree of real-life application of our findings (Antweiler and Muesgens, 2021).

This paper also relates to market power, defined as a firm's ability to profitably influence prices. Hydropower is a highly dispatchable generation source, and producers have been found to exercise market power by withholding production when trading on the Nord Pool electricity market (Kauppi and Liski, 2008). The intermittent nature of wind power prohibits such schemes. However, wind power producers can exercise market power by bidding strategically in the day-ahead and real-time electricity market to exploit peculiar bidding- and grid access rules, as proved by Yu et al. (2023) and Ito and Reguant (2016).

The findings also contribute to the literature regarding the interplay between incumbent firms and potential entrants in the RE-generating sector. In an entry-deterrence model applied to green technology investments, Strandholm and Espinola-Arredondo (2020) find that a monopolist can be incentivized to forego profits by underinvesting in research and development (R&D) given that it induces entry deterrence by restricting spillover effects to entrants.

A similar notion of entry deterrence by underinvesting in fixed cost reducing R&D is presented by Atallah (2007). On the other hand, Meunier and Finon (2023) find that incumbent electricity-generating firms are seldom able to deter entry by reduced production in a profitable way, suggesting that the underinvestment strategies lack commitment credibility and are thus redundant. Complementing this literature, we explore another strategic pattern of behavior for incumbent firms: they might deter entry by overinvesting in wind farms and idling on permits.

## 1.1 Research Questions

In this paper, we aim to answer the following two research questions:

1. To what extent do incumbent electricity-generating firms face diminishing incentives to expand wind power production due to market share effects, compared to domestic and foreign entrants?
2. Do these potential changes in incentives fully explain the investment patterns of foreign and domestic firms?

We employ a three-stage methodology to answer these questions.

First, we merge the four Swedish electricity bidding areas into two – north and south. A time series regression model is specified to estimate the merit order effect of additional wind power for each area. To analyze potential effects, we construct a core profitability framework based on two price bidding zones.

Secondly, we use the estimated merit order effect to populate the core profitability framework. This allows us to find the marginal profitability effect of additional wind power on an incumbent electricity producer in a short-run analysis. We allow for varying market shares in the bidding areas and assume that firms decide on production independently. Exploring a range of profitability-affecting factors, including transaction costs, financing costs, and accumulated experience, we contrast domestic and foreign entrants and identify the conditions under which foreign firms dominate.

Lastly, we relax the assumption of independent production setting and broaden the scope as part of a long-run equilibrium analysis to explore under what entry assumptions incumbent firms may still choose to expand. We show that incumbent investment choices depend on whether they can, or think that they can, affect entrant decisions through strategic deterrence in an entry-game context and outline the conditions for each investment pattern.

To the best of our knowledge, this is the first paper to quantify the merit order effect on an incumbent electricity producer's profitability depending on relative market shares in Sweden.

The rest of this paper is organized as follows. A background of the Swedish electricity market is presented in Section 2, and the related literature is commented on in Section 3. Section 4 contains the profitability framework and Section 5 the regression method. The data is presented and explained in Section 6. In Section 7, we show that the largest incumbent firms are heavily disincentivized to invest in wind power and illustrate how the investment decision relates to regional market shares. Analysis and discussion of the findings are located in Sections 8 and 9. In Section 10, we conclude.

# 2 Background

## 2.1 Electricity Market Overview

### 2.1.1 History and Deregulation

The Swedish economy was still characterized by agriculture when the gradual electrification process commenced in the early 1900s. The main electricity grid was developed by the 1930s, and the first transfer between northern and central Sweden took place during the same decade (Lindholm, 2017). In 1946, Vattenfall was assigned responsibility for all new lines in the power grid. This ultimately rendered them a long-lasting, market-dominating role. The position would be maintained as the firm became the largest producer and was assigned a general duty towards the market as a whole, according to the Swedish Energy Agency (SEA, 1998).

During the 1990s, the Swedish electricity market underwent a gradual transition culminating in liberalization on January 1st, 1996. The state-owned Vattenfall was transformed into a corporation in 1992 (SEA, 1998). As part of this process, the Swedish state separated the responsibility for the electricity grid from Vattenfall to the newly created government agency Svenska Kraftnät (SVK), with the purpose of taking steps towards increasing competition on the broader market (Molén, 1993). The foundational role of SVK is to ensure reliable transmissions of electricity from producers to distribution operators in its electrical grid. While electricity technically cannot be stored in the system, certain reserves can be deployed when necessary, and SVK is responsible for keeping the power system in balance at every moment. In Sweden, the government declares SVK's objectives, assignments, financing, and reporting requirements each year (SVK, 2023c).

A new law governing the electricity market was enacted in January 1996, deregulating several parts of the market. Consumers who previously had to purchase electricity from their regional concession holding distributor – bound to business with their respective line concession holder – could now choose freely, with some constraints (Bergman, 1997). The Swedish Energy Agency became responsible for monitoring and regulating the electricity grid, aiming to improve conditions for competition (SEA, 1998). Today, the production and sale of electricity in Sweden are competitive, while distribution remains monopolistic.

### 2.1.2 Regionalization

When the Swedish market was liberalized in 1996, the whole nation still consisted of one unitary market, in contrast to neighboring countries, most of which were split into multiple market zones (Granström et al., 2012). This arrangement would eventually come to an end. In 2006, Denmark made a complaint to the European Commission regarding SVK, arguing that the organization was withholding exports to make up for electricity deficits in southern Sweden. Ultimately, the complaint led to the European Commission mandating in 2010 that SVK deal with transferability constraints in the Swedish electricity grid. The Swedish electricity market was divided into four bidding areas in the subsequent year (EI, 2023).

The fundamental reason the Swedish market was split into four different bidding areas relates to physical bottlenecks regarding transmission in the electricity grid. While more energy is typically produced in the northern parts of Sweden, a majority of consumption occurs in the southern regions. When electricity demand exceeds transmission capacity, bottlenecks create price differences across the four bidding areas (SVK, 2023a). The regions have been split where the grids are insufficient to meet the demanded levels of transferability. SVK has the long-term responsibility of extending the underlying grids (EI, 2023).

## 2.2 Market Structure

Nord Pool is a European power exchange, operating daily wholesale electricity auctions as the main actor for the Nordic and Baltic regions. Roughly 77% of the wholesale electricity in the Nordic countries is traded on Nord Pool's day-ahead market Elspot, which determines the hourly price for each bidding area (Tangerås and Mauritzen, 2018). For each of the following day's 24 hours, supply and demand bids are aggregated and cleared to form a system price for the market as a whole. The Elspot market is a uniform price auction with marginal price setting. Hence, all bids are cleared at the marginal offer, which is determined by the cost of producing the final KWh to balance the system, or, put in other terms, the price that a consumer is willing to pay for the final KWh to fulfill demand. As a result, all producers are paid the uniform market clearing price per bidding area (Nord Pool, 2023).

The merit curve illustrates the marginal pricing mechanism, in which all production bids are ranked by short-run marginal costs:

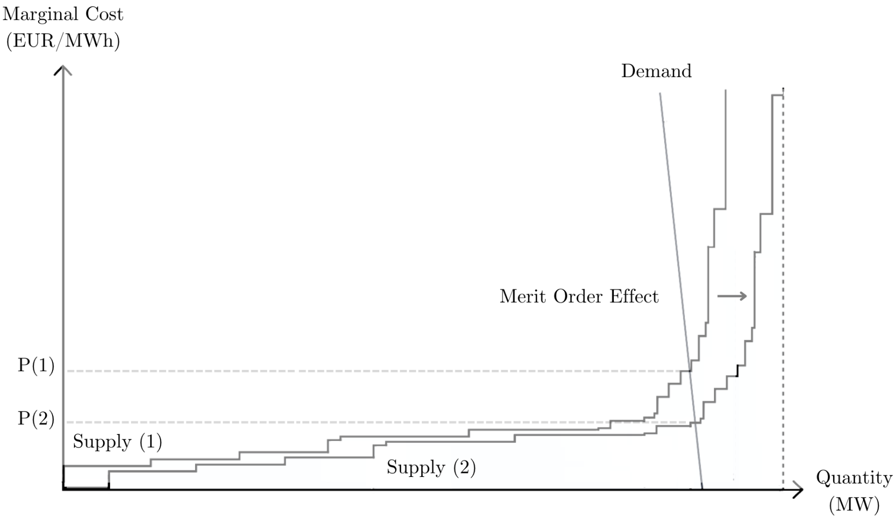

Figure 1: Illustration of the merit order effect

**Note:** This figure depicts the merit order effect of additional renewable energy. The price elasticity of electricity demand is commonly very inelastic, while the supply elasticity is partitioned, depending on the production source. The graph is based off of SVK (2022).

Since wind power is a renewable energy source that relies solely on the wind to generate electricity, it has a negligible marginal cost and is thus positioned to the very left in the merit curve. Additional wind power will push the merit curve to the right, displacing costlier conventional power production from the market. Thereby, the auction clears at a lower price. This process, known as the merit order effect, illustrates how wind power can reduce the wholesale electricity price under marginal pricing.

Each bidding area can have an electrical surplus, balance, or deficit, and electricity will flow from areas with low demand-to-production ratios to regions with higher demand ratios, independent of national borders. The system price holds for all hours in which there are no constraints in the transmission system. By contrast, when congestion occurs in the flow between bidding areas, the system price is dissolved into several regional prices, depending on where the congestion materializes[1]. Traditionally, the northern bidding areas have had excess electricity production due to extensive hydropower production while also being less densely populated. On the contrary, southern Sweden is more densely populated and lacks a vast hydropower output. Consequently, electricity within the country tends to flow from the north to the south, and when there is congestion, the prices are elevated in the south. Likewise, also note that electricity flows between Sweden and other Nordic countries on an hourly basis.

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[1] When the system price dissolves into regional prices, the bidding areas formally transform into price areas. We use the former notation for consistency throughout the paper

## 2.3 Production, Consumption and Policy

### 2.3.1 Supply of Energy

The supply of Swedish electricity has predominantly been produced by nuclear power and hydroelectric power plants since around the 1980s, and wind power production has grown steadily since around 2005. In 2021, around 60% of all electricity produced in Sweden originated from renewable sources and amounted to 165.5 terawatt hours (TWh). Hydroelectric and nuclear power represented 43% and 31% of the total production, respectively, with wind and thermal power reaching 17% and 9% (Statistics Sweden, 2022). During 2021, imports and exports decreased, with most exports directed toward Finland and imports stemming from Norway (Perez, 2022).

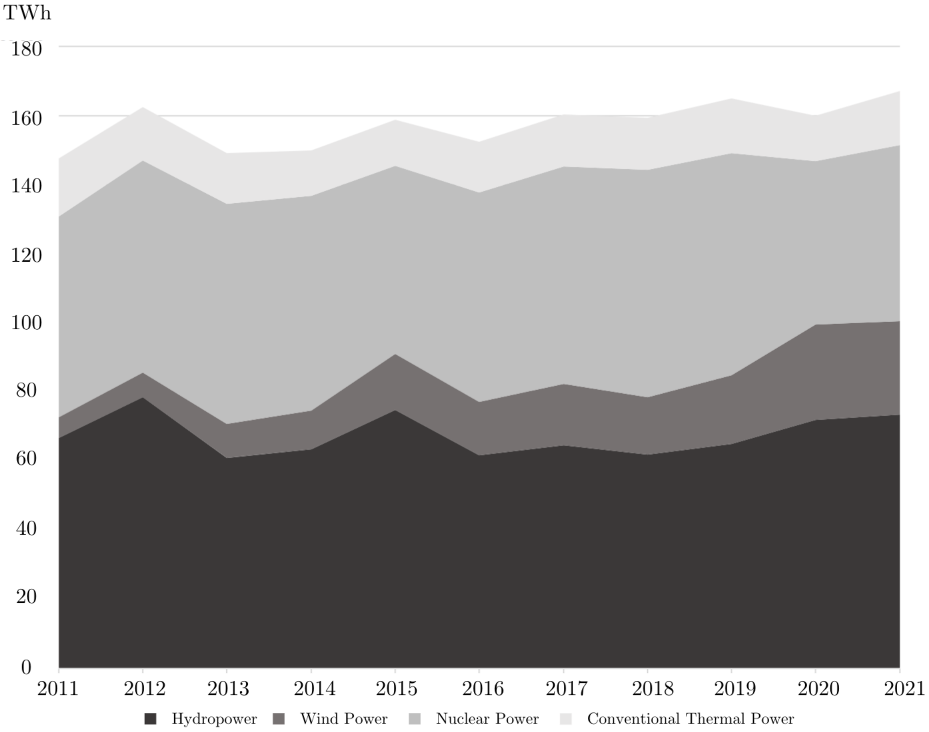

Figure 2: Major electricity production sources

**Note:** This figure shows the production from hydro, wind, nuclear, and thermal power in Sweden from 2011 to 2021. The data is obtained from Nord Pool.

The ownership of these various types of production technologies, and the evolution of their relative composition and market shares over time, has been subject to change. Five companies have dominated the production of electricity over the last 20 years. In 1996, these five firms produced 92.3% of the total electricity output in Sweden, a share that has decreased steadily to 73.5% in 2021. In 2020, foreign ownership accounted for 38% of the total capacity, of which 36 percentage points from state-owned firms, whilst Swedish state and municipal ownership amounted to 41% and 13%, respectively (Swedenergy, 2022, 2023b).

Notably, many large electricity producers in Sweden, such as Vattenfall AB, Fortum Power and Heat AB, and Sydkraft AB (Uniper) have had relatively diversified holdings of different production technologies. Vattenfall, for example, had 56% of its production in hydroelectric power, 35% in nuclear power, and minor shares of wind and thermal power at the beginning of 2017. Similarly, Fortum Power and Heat AB had 99% of their total production split across hydroelectric and nuclear power in early 2017 (Swedenergy, 2018).

A national or state-owned firm typically dominates non-renewable electricity production, as is the case for Vattenfall in Sweden. As part of exercising ownership, the Swedish Government published a clarifying proposition in 2010 regarding the mission of Vattenfall and its production. The overarching assignment for Vattenfall was clarified towards generating market-based returns through their energy operations so that the company helps lead the development of environmentally sustainable energy production (Swedish Parliament, 2010). In accordance with this, bonuses within Vattenfall relate to the financial performance of the underlying operations. This incentivizes managers within Vattenfall to act in favor of increasing profits when deciding on investments and production rather than necessarily focusing on social goals.

In contrast to the concentration of conventional energy, renewable electricity producers tend to be independent power producers (IPPs). Even if the production market is competitive, distribution monopolies or oligopolies can pose challenges to independent producers. Such challenges are mainly in the form of limited access to the electricity grid and insufficient grid ability to integrate the volatile renewable electricity generation, curtailing investments (OECD and IEA, 2008; Cosbey et al., 2008).

### 2.3.2 Electricity Demand

The electricity consumption in Sweden increased during the 1970s and 1980s as a shift from oil gradually took place, influenced by the expansion of nuclear power, all of which were located in the two southernmost zones. Thereafter, the consumption has remained relatively stable since 1985. The level of energy usage depends on several factors, including electricity prices, temperature, and industrial production levels. Sweden has quite an electricity-intensive industry, and while consumption has increased at a slower pace than GDP for several decades, macroeconomic conditions constitute an essential determinant of the overall demand (Statistics Sweden, 2022).

Electricity consumption is expected to face large-scale disruption as the electrification of industry, specifically the transport sector, advances as part of the Swedish transition to reduce greenhouse gas emissions. Significant industrial investments to reduce reliance on fossil fuels and carbon emissions are to be implemented, implying that a lot of new electricity production and transmission capacity will be needed to meet the growing demand. By 2035, the upper limit of estimated demand is 280 TWh, twice the usage of 140 TWh in 2022 (SEA, 2023a). The electricity production expansion rate must be historically high in the short term to meet the increased demand.

Wind power is envisioned to be one of the crucial factors in this evolution. Onshore wind power is the production source with adequate conditions in terms of technical and economic factors to add the largest increase in electricity production until 2035. In the long term, offshore wind and nuclear power expansion also have promising potential (SEA, 2023a).

### 2.3.3 Other Characteristics

Electricity generation sources can be categorized depending on whether they are dispatchable. Dispatchable production sources can be activated or deactivated in relatively short periods, allowing the output to be manipulated to fit demand. Hydropower, thermal, natural gas, and oil power plants are among such sources. Contrarily, wind and solar power are intermittent and non-dispatchable by nature as they require an input (wind and sunlight, respectively) that can neither be altered nor stored in the absence of sufficiently powerful batteries.

Electricity consumers can, to some extent, alter the demand to fit the price patterns that emerge due to intermittent supply. Demand response is the action of consumers to actively adjust their electricity usage during peak periods. Such programs are advantageous for balancing supply and demand, leading to cost savings. Two examples include charging an electric vehicle or running household electrical appliances at night. Such efforts are expected to grow with continued advancements in grid modernization, such as sensors perceiving peak load issues and smart customer systems, enabling effective demand response (Office of Electricity, 2023).

The price received for a unit of electricity production varies depending on the source. Each production has a corresponding capture price, as defined by, among others, Byrne et al. (2016):

$$\text{Capture Price (SEK/MWh)} = \frac{\text{Sum Revenue (SEK)}}{\text{Sum of Production (MWh)}} \tag{1}$$

The capture price is the average price the production source earns and does not necessarily equal the average wholesale market price. Nuclear power plants are more or less constantly producing electricity and will thus have a capture price equal, or very close to, the average price. On the contrary, non-dispatchable sources, such as wind power, produce intermittently and will thus earn a different capture price. During hours of high wind speeds, the merit order effect will reduce the average price, and due to a lack of demand response, wind power will cannibalize its own revenue. Therefore, wind power has an average capture price below the average market price. On the other end of the spectrum, peak demand generation such as coal and gas power plants, often operate when prices are high, thus earning a higher capture price than the average wholesale price. We define capture rate as the capture price divided by the wholesale price:

$$\text{Capture Rate (\%)} = \frac{\text{Capture Price (SEK/MWh)}}{\text{Average Wholesale Price (SEK/MWh)}} \tag{2}$$

Swedish onshore wind power has generally had an capture rate over 90%. Based on a continued wind power expansion, Sweco (2023) expects the capture rate to stabilize around 70-80% by 2050.

Buyers can also hedge electricity prices through Power Purchase Agreements (PPA), which is a type of long-term energy purchase agreement stipulating access to electricity at a fixed price. This type of agreement allows firms to manage financial risks more effectively, and only a minority of recent years' new investments into wind power production have been done without PPA agreements (SWEA, 2021).

#### 2.3.4 Certificates and Government Interventions

Sweden has had an electricity certificate system since 2003 to stimulate investments in renewable energy. Producers of renewable energy obtain one certificate for each MWh produced. The producers subsequently sell the certificates to those electricity suppliers with quota obligations, who must buy a certain amount of electricity certificates corresponding to a yearly allotment set by the government. The added costs suppliers incur when buying the electricity certificates are forwarded to consumers through increased electricity prices. Wind, solar, geothermal, some bioenergy, and some hydropower are the production sources that yield electricity certificates. The quota for 2023 is 27.1% and is expected to peak in 2029 at 30.4% (Östberg, 2017).

Since 2012, Sweden and Norway have had a common electricity certificate market. The scheme's objective has been increased multiple times to 33.2 TWh of new renewable electricity production in Sweden by 2030. The objective was achieved in March 2021 (SEA, 2021). Due to the success, reduced quotas are gradually phasing out the electricity certificate scheme until 2035, and no production facilities commissioned since 2022 are entitled to participate.

Numerous papers have shown that government renewable energy incentives are essential in promoting wind power. Feed-in tariffs (FIT), an incentive composing a determined add-on to the wholesale price, have been successful in promoting wind power and other renewables in a range of countries (Couture and Gagnon, 2010a; Lauber, 2004; Rowlands, 2005). Furthermore, societal benefits have been found to exceed credits paid in Spain and Ireland (Gil et al., 2012; O'Mahoney and Denny, 2011). Renewable portfolio standard (RPS), the system currently in place in Sweden with a fixed percentage of the energy mix to stem from renewables, may risk containing more uncertainty with regards to compensation and political interference (Lewis and Wiser, 2007).

## 2.4 Wind Power in Sweden

### 2.4.1 Industry and Development

Wind turbines can be located onshore or offshore. Even though both types entail the merit order effect and generate electricity using the same design and technique, there are some differences in characteristics between the two. On average, wind speeds are more predictive, stronger, and less volatile at sea. Yet, there have been many challenges historically with getting offshore projects approved. Offshore wind farms are typically larger, with higher costs and more extensive permit processes. The most extensive projects require approval from the government, which can prove to be an arduous process, and The Swedish Armed Forces often reject proposals (Lejestrand, 2023a). Since both generator types affect electricity prices in the same manner, we do not distinguish between production from onshore or offshore wind turbines in this paper.

The Swedish wind power market has undergone rapid change over the last decade. Between 2011 and 2022, total wind power production has increased from 6.1 TWh to 33.1 TWh, of which 97% is from turbines located onshore (SEA, 2023c). Most wind projects were initially developed in southern Sweden. This has changed as technology has developed, and today the northern regions have a slight majority of the national generator fleet after high levels of growth (SEA, 2023b).

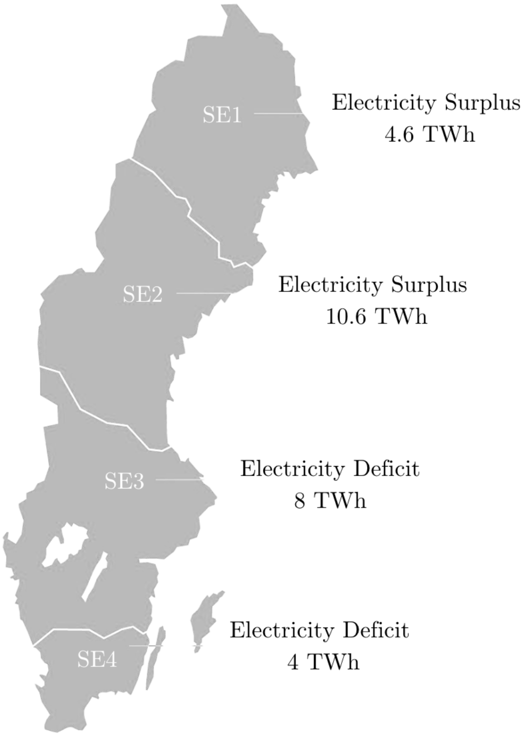

Figure 3: The four Swedish bidding areas

**Note:** This figure shows the wind power production for each of the four Swedish bidding areas for 2021.

By the end of 2021, 4835 wind turbines were installed, with a forecasted increase of 414 built by the end of 2022. New capacity of 1.76 GW is signed to be constructed between 2022 and 2024, against a three-year mean of around 2 GW per year, and power scores for existing turbines continue to increase year-on-year (SWEA, 2023).

There is also a lot of wind power activity at the firm level. Vattenfall's largest onshore wind farm, Blakliden Fäbodberget, is located in bidding zone SE2. Inaugurated in 2022, it produces about 1.1 TWh per year, corresponding to about 0.7% of total Swedish electricity production. The former monopolist also owns Kriegers Flak, Scandinavia's largest offshore wind park outside the coast of Denmark, in an area that constitutes an economic zone in both Sweden and Germany. In May of 2022, the Swedish government granted a construction permit for 35-50 wind turbines in the Swedish section of Kriegers Flak. This project would correspond to about 1.5% of total Swedish electricity production (2.7 TWh per year) and could be operational in 2028 (Vattenfall, 2023).

Furthermore, Vattenfall is currently building one of the world's largest wind farms, which is also the first subsidy-free European wind farm outside the coast of the Netherlands. It is set to be operational in 2023 and has a capacity of 1.5 GW. The park is co-owned to 49% by the German chemical conglomerate BASF, who will buy the same portion of the electricity generated to power their European production sites through a long-term PPA contract (Vattenfall, 2021).

The process behind the construction of a new wind turbine in Sweden consists of several steps (SWEA, 2023). Environmental permits must be granted before a new project can be commissioned, requiring an environmental assessment wherein social aspects play a role. Before such an assessment, both an early assessment and consultation process must be cleared, which evaluates grid requirements, local interests, and judgment of various perspectives. Typically, the entire process takes several years to complete, and only a limited share of planned projects are able to pass through this process (Lejestrand, 2023c).

Large wind turbines also require authorization from the municipality in which the wind turbines are to be located, and local politicians can leverage a veto to influence permit decisions. Municipalities have no direct financial incentives to issue the authorization, and residents may face negative externalities, such as natural disruption in the local environment. It has been empirically observed that more wind turbines in a municipality tend to lower the chance of future wind power authorization, possibly due to the lack of local incentives (Lundin, 2023).

### 2.4.2 Financial Components

The costs associated with constructing wind power turbines have changed significantly over time. The changes are driven to a large extent by increased turbine capacity, hub height, and larger rotors. These modifications have made it possible to increase the energy yield per turbine, ultimately rendering the industry more cost-efficient. Because new wind projects can take a long time to realize, it has historically been common that cost estimates change as the underlying technology develops rapidly (Kulin et al., 2016).

For an average Swedish wind farm, the fixed investment costs constitute around 70% of total project costs, and turbine costs represent around 70% of the investment costs. Due to the necessary size of capital investments, access to low-cost financing is critical for profitability during the lifetime of the turbines. The returns of any given wind power project can vary up to 20% depending on the capital return requirements, since access to low-cost capital is heterogeneous across firms (Energiforsk, 2021; Sweco, 2016). Similar studies on this topic have validated the importance of capital costs, confirming them as critical elements influencing total wind power generation costs (Blanco, 2009).

Building on this, a report published by the Swedish Energy Agency concluded that low capital return requirements, high-wind locations, and low costs would likely be defining characteristics of projects that will be built in the near future (Kulin et al., 2016). The importance of low-cost capital is likely to have increased since the report, as technological improvements have boosted the number and height of wind turbines for the average wind farm, increasing the total investment costs.

While wind carries negligible marginal costs, variable costs associated with wind are small but not inconsequential and include turbine maintenance, land lease, taxes, and other items (Blanco, 2009). These are estimated to be relatively homogeneous across firms and around 20 SEK per MWh for wind power production in Sweden (Energiforsk, 2021).

### 2.4.3 Ownership

In 2016, firms with foreign owners generated roughly a third of Swedish wind power. A shift emerged between 2017 and 2024. During this period, 85% of investments in Swedish wind power generation stem from foreign firms, and 65% of the total installed wind power capacity is estimated to have foreign ownership by 2024. Almost all wind power ownership is concentrated amongst private entities, and only 8% of the market will have public ownership by 2024. Many separate small firms will own a large combined share of the total market – it is estimated that up to 42% of the total installed effect will be controlled by firms with a market share below 1% (Swedish Television, 2022; SWEA, 2022).

Furthermore, there is a distinction between wind power owners and developers. The owner most often contracts a developer to execute the wind farm construction, but some developers sell wind farms during or after the construction. When operating, the owner maintains the asset and generates revenue from the sale of electricity. This thesis regards the ownership independent of how a project was or is developed.

Wind power producers can also outsource the maintenance and daily operations of the wind farm in long-term contracts. Outsourcing, together with the improved risk management of long-term

PPAs, has made wind power investments appealing to financial firms, which often have lower capital return requirements and a higher proportion of equity financing (Kulin et al., 2016; Energiforsk, 2021). Consequently, wind power ownership is distributed across several types of enterprises. Of the wind turbines estimated to be completed in Sweden between 2017 and 2024, asset management firms own 50%, energy companies 38%, pension funds 5%, and other firms around 6% (SEA, 2022).

# 3 Literature Review

## 3.1 Theory

### 3.1.1 General Structures of Perfect and Imperfect Competition

Markets can exhibit varying degrees of competition and, as a result, affect how firms and consumers interact in different ways. While perfect competition is on one side of the spectrum, a complete monopoly is on the other – with many potential models in between.

When markets are characterized by perfect competition, supplier and consumer market power is low. No single consumer can affect the market through individual purchase decisions, and no supplier can affect the price through individual quantities offered or supplied. In a competitive equilibrium, involved parties are price takers, and demand and supply meet where individually maximized utilities and profits find equality. In such an environment, demand can be described as the sum of individual consumer demands, where the individual quantity demanded depends on not only the price of individual good, $p$, but also income, $y_i$, and prices of other goods, $P$ (Jehle and Reny, 2011):

$$q_d(p) = \sum_{i \in I} q_i(p, P, y_i) \tag{3}$$

Similarly, total short-run supply can be described as the aggregate of individual sellers' output, where quantity varies depending on the price of the good, p, and variable inputs, W:

$$q_s(p) = \sum_{j \in J} q_j(p, W) \tag{4}$$

A short-run equilibrium is found where:

$$q_d(p) = q_s(p) \tag{5}$$

Such a short-run market differs in two important ways from a long-run equilibrium. While some inputs can be considered fixed in the short run, this is not the case in the long term. Another critical feature of a long-run equilibrium compared to a short-run market is that unprofitable firms will choose to exit, and potentially profitable companies likewise enter. Thus, in the long run, markets must be characterized by zero profits as well as market clearance.

Market competition, however, can exist along a spectrum of degrees. In stark contrast to the low market power environment, pure monopoly represents a situation in which one firm controls the market. In such a market, the monopolist maximizes profits conditional on demand function characteristics and no longer takes the price as given, as is the case in perfect competition. Instead, the monopoly outcome is dictated by the marginal revenue in relation to the marginal costs. A monopolist will continue to produce as long as there are profits to be made (Jehle and Reny, 2011):

$$\pi' = r'(q) - c'(q) = 0 \tag{6}$$

$$r'(q) = c'(q) \tag{7}$$

These are two market structures with relatively clearly defined mechanisms governing prices, quantities, and profit levels. Not all markets fit clearly into either of these environments and are rather somewhere in between.

### 3.1.2 Models of Wholesale Electricity Markets

Markets with a few competing firms are referred to as oligopolies. Such markets can be both highly competitive and share similarities with markets exhibiting perfect competition, as well as share traits with environments characterized by a monopoly (OECD, 2015).

An example of one such oligopoly model is that by Auguste Cournot. In a market characterized by Cournot oligopoly, firms compete through the quantities they choose to produce. All firms share a common market, and the price depends on the total quantity supplied. As the number of firms increases, the Cournot oligopoly model moves further away from the monopoly situation and the largest deviation from marginal cost. In a paper by Willems et al. (2009), the Cournot model is tested and compared with another more complicated Supply Function Equilibrium (SFE) model. Using German data, they note that the model frameworks are very different, each with strengths and weaknesses within different areas of use. While the Cournot oligopoly model is easier to set up and calculate, predicted prices are usually inaccurate.

In another paper, authors Lundin and Tangerås (2020) analyze and evaluate the performance of the Nordic electricity market. As part of this analysis, the authors must manage the fact that electricity exchanges, such as Nord Pool, do not always provide rich enough firm-level data for an extensive analysis of outside parties. To combat this, Lundin and Tangerås leverage the fact that requirements on data are lessened if companies submit bids inelastically when the wholesale market price is low. They conclude that individual firm power on the market is conditional on the properties of the aggregate inverse residual demand curve as opposed to individual curves, as part of a form of Cournot competition. Data to estimate such a curve is more widely accessible, and using data from 2011 to 2013, the authors reach several conclusions regarding the Nordic markets. They note that a "majority of within-week supply bid variation on Elspot stems from horizontal shifts in the supply curve," which is consistent with large firms competing in quantities. Moreover, they find evidence that the market is not exhibiting perfect competition. Their results indicate a price-cost margin of around 4%, and they reject the null hypothesis of perfect competition in all scenarios. The conclusions are complemented by a study of Hellmer and Wårell (2009). They find that the Swedish market was the only one in the Nordics with one firm that could, in short periods, be recognized as dominant.

Neuhoff et al. (2005) present another example of how the choice of model matters. They test the robustness of different models' results. The same data – from northwestern Europe – is used in three different electricity market models. The authors conclude that the three models reach the same results when competition is assumed to be perfect, but outcomes deviate when a Cournot model is employed. They further highlight three core challenges within strategic models. The primary issue regards how different parts of the electricity market relate to each other. They note challenges related to whether strategic generators believe that other generators are affected by their decisions regarding their own output. Moreover, they discuss how the design of the markets matter, and comment that it could be possible that generator output solely depends on local demand elasticities. Lastly, they also discuss bounded rationality and to what extent generators make generalizing assumptions or reduce complexity in other ways. This paper indicates that the assumptions about generators – their beliefs and potentially bounded logic – matters.

## 3.2 Market Power

The exercise of market power, both in the Nordic electricity market and segmented by renewable energy sources, is well documented in empirical research. Fridolfsson and Tangerås (2008) review prevailing research on market power in the Nordic wholesale electricity market. They find conflicting results and note that while simulation-based models show consistent market power on the market, other papers de-emphasize such mechanisms. Kauppi and Liski (2008) find market power patterns indicating that 30% of hydro reservoirs in the Nordics between 2000 and 2005 was strategically managed, elevating prices and price volatility. In contrast, Edin (2006) deduces that, on average, the price difference between the Nordic system price and an alternative competitive price is small enough to constitute a competitive market. While the authors conclude that electricity producers exploit regional market power due to transmission constraints, they find no conclusive proof of flagrant and systematic exploitation of market power at the system level. They also note the need for future research to determine how investment obstacles and the use of market power affect incumbent electricity-generating firms' conceivable incentive to underinvest in production capacity.

Even though wind power generation is intermittent and not easily subject to altered production levels, wind power producers can exercise market power to some extent, as demonstrated by Yu et al. (2023). Conventional energy and wind power generation differ in bidding rules and grid access rules. Typically, electricity producers only place one set of supply curve bids in the day-ahead market due to constant fuel costs and have limited possibility to increase production from one hour to the next due to ramp-up constraints. Moreover, they are required to guarantee to produce at least their bids in the day-ahead auction, while wind power producers are allowed to purchase external electricity generation in the real-time market if they fail to meet their commitments in the day-ahead market.

Using a market of three production sources and two consecutive hours, Yu et al. explore how wind power producers can exercise market power by placing strategic supply bids that exploit ramp-up constraints of other production sources. The authors find that wind power producers can manipulate wholesale prices to their favor by placing lower or higher quantity bids than their forecasted quantity for pairs of hours, depending on competitors' ramp-up capabilities. Simulating the Texas ERCOT electricity market during 2020 indicates that wind power producers were incentivized to employ strategic bidding for most hour-pairs. Solidifying these findings, Ito and Reguant (2016) find that dominant firms with market power tend to employ similar strategies by retaining wind power production in the day-ahead market to sell more in the real-time market.

## 3.3 Incumbent-Entrant Dynamics

The interplay between incumbent firms and potential entrants is also an area of extensive research. Under the assumption of bidirectional technology spillovers, Atallah (2007) studies an incumbent monopolist's ability to deter entry by underinvesting in cost-reducing R&D. Such underinvestment is used to limit technological spillovers to an entrant and ultimately increases fixed costs for both incumbent and potential entrant. The author observes that entry-deterring underinvestment in R&D is more probable to constitute an equilibrium when the net spillover effect of the incumbent is weaker than for the entrant and when the level of fixed cost is moderate.

Closer to our topic of RE generation, Strandholm and Espinola-Arredondo (2020) use an entry-deterrence model to study green technology investments with research and development as a core component. More specifically, the authors investigate the effect of emission fees and regulation on entry deterrence in a model with spillover effects only originating from the incumbent firm. Using a framework with three decision stages and Cournot competition in the case of entry, they find that incumbent decisions depend on whether they face the threat of entry. The results indicate that an incumbent monopolist generally has low incentives to invest in R&D, and an incumbent firm prefers to deter entry under sufficiently high entry costs and intermediate spillover effects. The authors conclude that such an equilibrium is not socially optimal.

The fact that incumbents' actions may depend on the existence of potential entrants is also evident under other forms of market competition. Meunier and Finon (2023) study entry deterrence on electricity markets under oligopolistic competition without economies of scale. They find that incumbents oftentimes are not able to deter entry profitably, and without scale economies, entry can only be deterred if the incumbent firm is more efficient than the entrant. Furthermore, they show that forward markets can help incumbents deter entrants through allowing for production commitments to be made. Concludingly, they reinforce the idea that incumbent output and product decisions may be sensitive to whether they face the threat of potential entry.

## 3.4 Merit Order Effect of Wind Power

The fact that wind power is expected to reduce electricity prices in the short run due to its negligible marginal cost – referred to as the merit order effect – has been studied vastly. Würzburg et al. (2013) present a meta-analysis of relevant past research on this dynamic, in which all simulation-based studies indicate a negative price impact for Germany and Spain, see Woll and Weber (2007), Weigt (2009), Traber et al. (2011), and Traber and Kemfert (2011). More related to our study, a range of empirical studies are also presented. Gelabert et al. (2011) utilizes daily production outputs for 2005-2009 to conclude that a supplementary GWh of renewable energy generated in Spain reduced wholesale prices by approximately 2 €/MWh.

De Miera et al. (2008) find a similar relation in Spain with a different methodology, analyzing three consecutive day-hour pairs with similar levels of demand and substantial discrepancies in wind production outputs. They find that wind production in Spain, at the time corresponding to roughly 10% of demand, reduces prices by 9-25% compared to a scenario without wind production. Gil et al. (2012) similarly find electricity production with wind power to be, on average, 18% lower than an energy mix without wind power, using a conditional probability procedure with hourly data for day-ahead electricity prices in Spain from 2007-2010. Ketterer (2014) utilizes a GARCH model to evaluate wind power's effect on volatility and electricity prices based on daily data for the years 2006-2012. The results indicate increased volatility and reduced price, with a 1% increase in wind output associated with a 0.1% reduction in price.

Several studies have been conducted depicting wind power's effect on wholesale electricity price with an OLS approach. O'Mahoney and Denny (2011) use hourly Irish data wind production in an OLS regression approach with price as the dependent variable, controlling for net demand, marginal capacity, and prices of coal and gas. They define net demand as total system demand minus demand that is met through peat output and imports, as these sources are not price-setting in the Irish context. Comparable to other studies, they found that adding one GW of wind power led to a decrease in electricity prices by 9.9 €/MWh.

Woo et al. (2011) use a one-lag autoregression methodology for the four bidding zones in Texas, with 15-minute interval data for 2007-2010. In addition to wind power production, the model incorporates nuclear power production, system load in each of the zones, gas prices, and a series of time dummies. They find that a 100 MWh increase in wind power generation reduces electricity prices by 1.3-4.4 $/MWh in the zones. According to Zarnikau (2011), inadequate transmission capacity in Texas has resulted in a scenario where fluctuating wind power generation has caused electricity prices to drop in certain areas and surge in others. Baldick (2011) adds that Texas' considerable electricity price instability can be attributed to the inverse relationship between wind power production and peak demand.

A recent study by Macedo et al. (2021) examines the effect of wind power and electricity inflow and outflow on day-ahead electricity prices in the Swedish bidding zone SE3. Using a non-conventional setup, they analyze each hour of the day separately to account for strong potential seasonality. The 24 different models are estimated with a seasonal autoregressive moving average approach from January 2016 to April 2020. They find consistent proof for the merit order effect during all hours of the day, with relatively homogeneous coefficients across the hours. A 1% increase in SE3 wind power production decreases electricity price for a given hour by 0.019-0.061%, with the highest magnitude between 07:00 and 09:00.

While there are robust findings of the merit order effect presenting in the short term, there is more ambiguity about whether the effect is simply a temporary phase or an influence that will sustain in the long term. Antweiler and Muesgens (2021) argue that the power market might adjust to the lower prices by expanding electricity consumption over time, subsequently increasing the price. They study the impact of introducing intermittent renewable energy sources into an existing energy mix without renewables. They do this using two different scenarios. In the first scenario, the conventional energy producers do not adjust to the introduction of renewables, while the second scenario has a full long-term adjustment of said capacity. Both cases are investigated under perfect and monopolistic competition for the conventional base and peak load. They find most of the reduction in price due to increased renewable energy generation to be transitory. Moreover, under certain specific assumptions in the perfect competition scenario, the long-term merit order effect diminishes fully. The assumptions include constant variable and fixed costs of a conventional base load generator operating optimally both before and after the introduction of renewables. In contrast, the merit order effect will always hold in monopolistic settings. The additional renewable energy will reduce base load capacity that could be withheld from the market, reducing incentives to exercise market power. This also holds for oligopolistic markets.

## 3.5 Investments and Foreign Ownership

### 3.5.1 Profitability and Expansion

As the merit order effect appears to exist, at least in the short term, the question of how investment decisions are made and profitability is considered arises. Even if renewable electricity sources have negligible marginal costs and technological leaps have made them more economically viable, they are volatile by nature and can carry uncertainty to a market. Wind power, for example, carries uncertainty relating to volatile wind speeds, and the introduction of large wind farms can affect market dynamics (Karanfil and Li, 2017). Mokhtari and Yen (2021) evaluate how the expansion of wind power relates to the investment's profitability and seeks to model a firm's decision-making process in renewable electricity generation, taking the uncertainty of wind power production into account. They do this by conceptualizing a framework comparing the profitability of two markets over ten years; one with only fossil fuel plants and one with fossil fuel plants and wind power. The second market models scenarios on the uncertain wind generation, using an approach of wind power producers as price takers due to their assumed inability to forecast wind in the day-ahead auction.

The results found by Mokhtari and Yen (2021) indicate that a 1 m/s deviation in hourly forecasted wind speed reduces the hourly profitability by 3.4% in the most volatile scenario, ultimately showcasing that wind speed uncertainty does not have a major impact on locational investment decisions. However, they find that reduced profitability due to higher wind power penetration may move the needle on the final investment decision. High wind power penetration in a market lowers the average profit of investors with both fossil and renewable energy generation. Even though they do not investigate the nuances of this relation, they conclude that the situation is less adverse for investors with higher wind-to-fossil ratio, since wind power essentially removes the demand for fossil fuel power through the merit order.

### 3.5.2 Foreign Direct Investment

Markets are typically subject to a wide range of imperfections. Transaction costs, as defined by Coase (1960), consist primarily of negotiation costs and information acquisition costs and compose some of the wide arrays of market imperfections. Furubotn and Richter (1998) extend the definition to include all costs associated with creating, operating, and maintaining firms. Following Wink Junior et al. (2011), we define transaction costs as costs related to constructing contracts (research and information), signing contracts (negotiation and decision-making), and monitoring and enforcing contracts. These elements constitute the cost and degree of difficulty in doing business, and foreign firms have been found to have higher transaction costs. Language barriers are one foreign-specific transaction cost that reduce the level of FDI (Oh et al., 2011).

There is a plethora of literature on foreign direct investments (FDI) and its presumable effect on growth and associated externalities of the host country, in addition to the direct capital invested. Fernandes and Paunov (2012) show that FDI positively impacts innovation and productivity in manufacturing. Batten and Vo (2009) present proof that the mediating factors in which FDI positively affects growth include technology adoption and transfer, as well as spillover effects such as managerial skills. Lee (2013) extends this research to gather the effect of increased total net FDI on economic growth and clean energy use in the G20 countries during 1971-2009. While the positive relation to economic growth is validated, the effect on clean energy usage is more ambiguous. Results indicate that FDI net inflows are not necessarily associated with an increase.

Numerous host-country characteristics affect the allurement of foreign direct investments. Market size, skillness of labor, technology level, and earlier export patterns are among the factors, as found by Braunerhjelm and Svensson (1996) and others.

Related to this paper's topic, Hanni et al. (2011) study the drivers and determinants of foreign direct investments in renewable energy generation, using global firm data from 2003-2010 on electricity-generating wind, solar, hydro, and biomass projects. Their data shows that a majority of the FDI projects during the period were done in European countries, largely due to the early application of renewable energy commitments in the zone. Utilizing a conceptual framework by UNCTAD (2010) of four categorial drivers for renewable energy generating projects, they uncover the main reasons firms conduct renewable FDI. These include saturated home markets, first-mover advantages to exploit accumulated experience and know-how, and emerging opportunities abroad in terms of government incentives. The authors also note that economies with a developed technological base tend to invest more in other countries, which explains why German and Spanish firms are active investors in other European countries and account for most of the renewable energy generation FDI in Europe.

Regarding the policy framework of a potential host country, the most critical aspects are FDI entry criteria, long-term renewable electricity usage targets, electricity market regulation, and market establishment policies such as electricity certificates or feed-in tariffs. Hanni et al. (2011) also note that home country government-backed export credit agencies can alleviate risks associated with renewable energy investments, as has been implemented in Denmark. Partnerships can also be formed to encourage cross-country M&A and FDI activity by reducing transaction costs, even though they are rare. Nonetheless, a Swedish-Chinese partnership on energy conservation and protection cooperation is mentioned, in addition to an EU-China partnership aimed at inducing market entry for low-carbon firms in both markets.

On a similar note, LV and Spigarelli (2016) study locational choices of Chinese foreign direct investments in the European renewable energy sector. They analyze the role of host country institutional factors on the endowment of Chinese foreign investments in the EU, using firm-level data to perform a logit analysis. The results indicate that Chinese firms value similar market factors when deciding on host countries for foreign investments. Among those factors are large market size and high market affluence. Furthermore, while they value a stable political environment in the host country, low levels of corruption, and low trade barriers, the study finds that Chinese companies prefer host countries with a weaker rule of law. The authors also note that the importance of these factors depends on the function of the overseas subsidiaries.

The locational choices do not only vary across countries, but also within countries, as investigated by Lundin (2022). Lundin studies the effects of the Swedish market splitting reform in 2011 on locational choices of wind power investments. Using a difference-in-differences method for estimating heterogeneous variation in investments across electricity price areas, the findings show a new preference for where investments were made geographically. Due to the reform, almost 20% of large operator wind power projects were allocated to the southern bidding areas with higher prices. Lundin concludes that the new locational pattern was not driven by changes in geographical characteristics, indicating that investor behaviors had changed due to the reforms. These conclusions, however, could mainly be drawn for larger firms, and small firms did not appear to change their behaviors.

To summarize, various studies have analyzed time series data on electricity prices across a range of systems, and the short-term merit order effect is demonstrated to hold in many different markets: more wind power tends to reduce wholesale electricity prices. There has also been extensive research into what factors affect domestic and international energy investments on a general level. With this paper, we seek to extend the discussion and gain a better understanding of how the merit order effect affects wind power investment incentives. Specifically, we extend the literature by looking at how differences in total electricity market ownership and firm origin may play a role. This becomes especially interesting considering that the Swedish electricity market has undergone large changes over the last decades, with wind power generation growing substantially. Moreover, we also extend the current literature by considering how potential merit order effects differ across electricity bidding areas within the same country. Since transmission constraints and congestion drive differences in prices across bidding areas, allowing for geographical differences in investment incentives helps nuance the current green literature.

# 4 Model

We propose a two-part framework to estimate the merit order effect and assess how firm investment incentives shift depending on relative market shares. In Section 4.1 and 4.2, we illustrate the components of firm profitability, and outline the general decision-making process of an electricity-generating firm. Building on this, we present a core profitability framework in Section 4.3. This model depicts profitability implications using two distinct bidding zones and allows for varying degrees of ownership across firms.

## 4.1 A General Profit Function

The literature presents many possible avenues to describe the profit function of an electricity-generating firm in an oligopoly market under Cournot competition (Shafie-Khah et al., 2016; Neto et al., 2016; Chen and Zhu, 2020). This paper looks specifically at understanding the core effects of an expansion in wind power generation, and we thus segment the parameters associated with wind. In a generalized fashion, the profit relationship may be described as follows:

$$\pi_{firm} = Q_{wind}(P - VC_{wind}) + Q_{other}(P - VC_{other}) - (FC_{wind} + FC_{other}) \tag{8}$$

Throughout the next sections, we will assume that firm profits depend on the wholesale electricity price, variable costs, and fixed costs. $Q_{wind}$ denotes the quantity of wind produced by the firm and $Q_{other}$ all other production by the firm. In this simplified specification, we assume all production to be subject to the wholesale market price $P$. $VC$ represents variable costs, and $FC$ represents fixed costs. In the following sections, we consider a form of derivative of firm profits with respect to the quantity of wind, explicitly accounting for the merit order effect in a distinction between generation of new units and already existing production.

## 4.2 A Simplified Investment Decision

The current literature indicates that the electricity market may effectively be described as a form of Cournot oligopoly with imperfect competition. The profit function specified in Equation (8) is an illustration of this market type. In this section, we model a simplified investment decision. Firms decide whether to invest independently of others, and only consider their own influence on the merit order effect. This is presented to show that firms are sensitive to the levels of additional revenues, losses on existing production as well as fixed costs – even in a reduced scheme.

In a simplified model, profit-maximizing firms will invest into wind power generation if:

$$\pi_{NEW} = \pi_{newproduction} + \pi_{oldproduction}|expansion > \pi_{OLD} = \pi_{oldproduction} \tag{9}$$

where:

$$\pi_{newproduction} = Q_{new}([P + Q_{new}MOE_{new}] - VC_{new}) - FC_{new} \tag{10}$$

$$\pi_{oldproduction} = Q_{old}([P + Q_{new}MOE_{new}] - VC_{old}) - FC_{old} \tag{11}$$

$$\pi_{oldproduction} = Q_{old}(P - VC_{old}) - FC_{old} \tag{12}$$

In this model, new wind power generation is segmented from all pre-existing production. $Q_{new}$, $VC_{new}$, and $FC_{new}$ represent the quantity, variable cost, and fixed costs of a firm's additional wind power production. For simplicity, we again homogenize a firm's total pre-existing production, independent of type, to $Q_{old}$ and continue to assume all production is subject to the uniform price $P$. In Equation (10) and (11), $MOE_{new}$ is the change in wholesale price attributed to one additional unit of wind power production due to the merit order effect. This variable is assumed to be negative. The subscript $_{old}$ denotes pre-existing production parameters and follows the same format as the parameters denoted $_{new}$. An underlying assumption in this reduced model is that $Q_{old}$ does not change as new production is added.

Substituting (10), (11), and (12) into (9) yields:

$$\begin{aligned} \pi_{NEW} = \; & + Q_{new}([P + Q_{new}MOE_{new}] - VC_{new}) \\ & - Q_{old}([P + Q_{new}MOE_{new}] - VC_{old}) \\ & - (F_{new} + F_{old}) \\ & > \pi_{oldproduction} = Q_{old}(P - VC_{old}) - F_{old} \end{aligned} \tag{13}$$

Subtracting on each side and rearranging further yields:

$$\begin{aligned} \pi_{NEW} - \pi_{OLD} = \; & + Q_{new}([P + Q_{new}MOE_{new}] - VC_{new}) \\ & + Q_{new}Q_{old}MOE_{new} - FC_{new} > 0 \end{aligned} \tag{14}$$

Ultimately, this simplified model illustrates that a firm's pre-existing production level and the magnitude of the merit order effect both matter in the investment decision. When firms increase their wind power output, they gain revenues from the new production they sell on the market and simultaneously slightly reduce the price of all other production. In the next section, we introduce other firms as well as price bidding areas into this model and derive a core profitability framework that will be used to answer the research questions.

## 4.3 Core Profitability Framework

In this section, we present the framework that will be used to analyze changes in firm-level profitability throughout the rest of the paper. Building on the current literature and the simplified models in the previous sections, we derive a function that relates changes in wind power production to hourly profitability. The profitability framework allows for the merit order effect to differ across two price bidding areas and lets firm profits depend on other firms' actions. As before, a distinction is made between new and existing production:

$$\begin{aligned} \triangle Profit_{firm} = \; & + I(Price_{local} + MOE_{local} I - VC) \\ & + (I + J)(share_{local} MP_{local} MOE_{local}) \\ & + (I + J)(share_{non-local} MP_{non-local} MOE_{non-local}) \\ & - FC \end{aligned} \tag{15}$$

where:

$I$ = The increase in hourly wind power production by the firm

$J$ = The increase in total hourly wind power production by all other firms

and:

$Price_{local}$ = The local electricity price

$share_a$ = The firm's share of the electricity production in area $a$

$MP_a$ = Average hourly market electricity production in area $a$

$MOE_a$ = Price effect in area $a$ per additional MWh wind power production in local area

$VC$ = Variable costs per additional MWh of wind power production

$FC$ = Fixed costs per additional MWh of wind power production

$a$ = Local area, non-local area

### 4.3.1 Framework Components

Within the framework specified in Equation (15), investments can be made either in the north or in the south. The area where an investment is made is referred to as the local area, while the other area is denoted as the non-local area. There are four distinct components to the core framework:

A) New units of wind power will increase revenues:

$$I(Price_{local} + MOE_{local} I - VC) \tag{16}$$

B) Revenues on existing local production will change:

$$(I + J)(share_{local} * MP_{local} * MOE_{local}) \tag{17}$$

C) Revenues on existing non-local production will change:

$$(I + J)(share_{non-local} * MP_{non-local} * MOE_{non-local}) \tag{18}$$

D) Fixed costs may increase with the additional production:

$$-FC \tag{19}$$

One more unit of wind power produced by a firm renders new revenues (A). For each additional unit produced, I, the firm receives the average local price adjusted by the merit order effect. As illustrated in Section 4.3, the merit order effect also influences all existing production and can be driven either by the firm itself through its own production increase, $I$, or by other firms, $J$. Therefore, a firm with pre-existing production will lose some profit on existing units as additional wind power decreases the average electricity price, regardless if the firm itself or another firm produces it. This impacts the firm both where the investment is made (B) and where it is not made (C). Finally, the size of the associated fixed costs ($FC$) also affects the total change in profitability.

Similar to the simplified logic in Section 4.2, firms will choose to invest as long as it leaves them better off in expectation:

$$E[\triangle Profit_{firm}] > 0 \tag{20}$$

### 4.3.2 Assumptions in the Short and Long run

In our analysis, we will differentiate between a short-run and a long-run analysis.

In the short run, we assume that firms can only predict their own actions – and thus only consider how their own actions affect their own profitability. Then, $J = 0$, and the core profitability framework will be:

$$\begin{aligned}\triangle Profit_{firm}|J=0= \; & +I(Price_{local}+MOE_{local}I-VC)\\ & +I(share_{local}MP_{local}MOE_{local})\\ & +I(share_{non-local}MP_{non-local}MOE_{non-local})\\ & -FC\end{aligned} \tag{21}$$

In a long run analysis, we relax this assumption and instead assume that firms believe that entry is possible by other firms. Then, $J \geq 0$.

However, the framework does not imply that firms do not also take entrance costs, financing costs, capture rates or capital return requirements into account when considering investments. The opposite is true – the current literature suggests these factors are taken into consideration to a high degree (Oh et al., 2011; Blanco, 2009; Kulin et al., 2016). Either directly or indirectly, such components are included in variable and fixed investment costs.

This limited model illustrates the implications of additional wind power on a firm's earnings, given different levels of market shares and price cannibalization. Thus, it acts as a foundation for extended analysis. Limitations are covered further in Section 9.2.

# 5 Empirical Method

In this section, we specify a time series MLR regression model to estimate the merit order effect of wind power production across the two bidding zones. The results are used to populate the core profitability framework to analyze the research questions.

## 5.1 Regression Specification

Estimating the effect of a change in wind power production on the wholesale electricity price requires a comprehensive explanatory model. Supply and demand are set simultaneously within the Nord Pool auction systems, and the electricity system must balance at all times. Because of this simultaneity, it is not possible to estimate either a demand or a supply function separately in a reliable way, as they depend on each other. However, at equilibrium, we know that the quantity supplied must equal the quantity demanded, which allows us to estimate electricity prices using OLS (Parker, 2010).

We determine the effect of wind power production on wholesale electricity prices by estimating the following fixed effects specification:

$$\begin{aligned}P_{t,a} = \; & \beta_0+\beta_1 Wind_{t,north}+\beta_2 Wind_{t,south}+\beta_3 Nuclear_t+\beta_4 Inflow_t+\beta_5 Coal_t\\ & +\beta_6 PVI_t+\beta_7 temp_{t,north}+\beta_8 temp_{t,south}+\phi_Y+\psi_M+\omega_W+\theta_D+\kappa_H+\epsilon_{t,a}\end{aligned} \tag{22}$$

The dependent variable is wholesale electricity price $P$ at hour $t$ in area $a$. We expect wind production to be short-run exogenous to electricity price, conditional on temperatures ($temp$), domestic production value index ($PVI$), nuclear power production ($Nuclear$), and inputs of thermal ($Coal$) and hydropower ($Inflow$).

We estimate one set of coefficients for the northern bidding area and one set for the southern bidding area. The variables of interest are $Wind_{t,north}$ and $Wind_{t,south}$ captured by parameters $\beta_1$ and $\beta_2$, respectively. The time fixed effects are sets of binary indicators of year ($\phi_Y$), month of the year ($\psi_M$), week of the year ($\omega_W$), day of the week ($\theta_D$), and hour of the day ($\kappa_H$). We also run alternative specifications, including different sets of time fixed effects and control variables, to show the robustness of our results.

The underlying assumption is that the quantity supplied for a given hour can be estimated by the electricity price, wind, and nuclear power production for each bidding area, water inflow, and coal prices while controlling for area-specific temperatures and time fixed effects. Correspondingly, we assume that the quantity demanded for a given hour can be estimated by the electricity price, area-specific temperatures, and monthly production value index data, conditional on time fixed effects. The quantity supplied will equal the quantity demanded in equilibrium. See Appendix section A for the thorough model derivation with specifications for supply and demand.

## 5.2 Selection of Variables

Estimating the electricity price using all the actual production quantities as independent variables would likely render an endogeneity problem. For example, it is reasonable to assume that higher electricity prices incentivize some electricity producers to increase production to exploit the elevated prices, undermining the model. In this case, it is essential to distinguish the potentially problematic dispatchable production sources from the non-dispatchable production. For this reason, we do not use the hourly production data on hydropower and thermal power; we instead use the variables $Inflow$ and $Coal$.

Hydropower generation is dependent on water inflow to hydropower plants and reservoirs, with most of the inflow going directly to the power plants without being stored in a reservoir (Johannesson, 2018). Water inflow constitutes precipitation and melting snow, making it more exogenous to electricity prices. It is denoted in the corresponding amount of energy generated that can be extracted from it. As it is both the input to hydropower generation and relatively exogenously determined in relation to price, we include it as an explanatory variable. Changes in this variable are expected to be negatively associated with wholesale price because of hydropower's relative position in the merit order, with low marginal costs.

Swedish thermal electricity generation includes several energy sources, including coal, oil, biomass, and waste. While coal is not the major thermal generation input, it is easy to obtain reliable data on and it represents a significant electricity source in neighboring countries such as Denmark, Poland, and the Baltics, which are interconnected with the Swedish electricity market. As a result, the international coal price may affect the electricity supply in Sweden, and we therefore use it as a proxy for thermal generation. While hydropower is expected to be negatively associated with the electricity wholesale price, coal is relatively expensive on the margin and likely has an opposite relation to price-levels.

Nuclear electricity production is baseload and practically constantly operating at full capacity in Sweden except for times of maintenance. Therefore, we follow Woo et al. (2011) and categorize it as non-dispatchable, allowing it to be included in the model as-is. A-priori beliefs from the current literature indicate that nuclear energy is negatively correlated with wholesale prices.

We also control for temperature, as it has proven effective in explaining variations in electricity demand. Feinberg and Genethliou (2005) deem weather the most critical factor in short-term demand forecasts, with temperature being the most commonly used parameter. As it gets colder, more energy is required to heat buildings to keep a comfortable indoor temperature. In the U.S., temperature and electricity demand have a U-shaped relationship due to increased heating during low temperatures and the extended use of air conditioning during high temperatures (Cottet and Smith, 2003; Engle et al., 1986). In contrast, Swedish summers are rarely blazing enough to attain widespread use of air conditioning, causing the relationship between temperature and electricity demand to be strictly negative (Neamtu, 2016). Other parameters, such as illumination or snowfall, can impact electricity demand by altering the *perceived* temperature. However, these parameters are second-order effects and will, therefore, not be incorporated. We also include the Swedish production value index ($PVI$) as a control to capture demand more extensively. $PVI$ is a uniform measure of the monthly evolution of trade, services, and goods production in Sweden, broadly capturing the economic output level of firms.

## 5.3 Robustness

Time fixed effects are included in the specification to account for time-varying unobservables. It is critical to differentiate between different days of the week because there are large differences in consumption patterns over the course of a week, primarily between weekdays and weekends, due to work schedules. Moreover, electricity demand is very inelastic and follows a cyclical hourly pattern during a full day. Swedish electricity demand tends to be elevated during the daytime, with peak demand in the morning between 06.00 and 08.00 and in the evening between 16.00 and 22.00 (Karimu et al., 2022). Therefore, we include a set of dummy variables to account for the hour of the day. Furthermore, week controls allow us to capture effects arising from recurring events, such as week-specific holidays that shift little year-to-year, and that may potentially be related to both wind power generation and prices simultaneously. Lastly, including monthly and yearly controls allow us to capture long-term price and production trends and seasons that may affect our coefficients. General production levels, primarily wind generation, have developed significantly over time, and there are recurring price patterns over the year, which such controls account for.

The regression model is explicitly specified to capture the effect of wind power generation on wholesale electricity prices. The aim is to estimate the average price effect of wind power, not predicting the prices from one hour to the next. For this reason, we do not include lagged variables. Doing so would likely decrease the magnitude of coefficients and could potentially lead to multicollinearity interpretation issues in these variables. This specification is expected to provide unbiased estimates, and the standard errors are treated as outlined in Results, Section 7, as well as in Appendix section B, which contains supplementary regression estimations.

Although the electricity price in Sweden is related to the electricity demand and supply in neighboring countries trading on Nord Pool, the most significant effect of the common market is when congestion occurs between borders. Ideally, one would widen the scope of analysis to include data from each bidding area in Nord Pool and account for transmission to and from the Swedish bidding areas. Although not completely, our model incorporates such aspects to an extent. Coal is a fundamental electricity source in several other countries trading on Nord Pool, and the international coal price, therefore, provides auxiliary explanatory power. Moreover, the Swedish weather patterns, such as temperature and water inflow, may, to some extent, covariate with patterns in neighboring countries.

# 6 Data

## 6.1 Data Sources

We collect data on hourly wholesale electricity prices for each bidding area from the Nordic power exchange Nord Pool[2]. The data originates from the daily auction Elspot, which determines the day-ahead prices for each of the 24 hours for the following day. To depict electricity production, we gather hourly data for each production class and bidding area from Svenska Kraftnät (2023b). Moreover, we collect hourly temperature data from the Swedish Meteorological and Hydrological Institute (SMHI) for each bidding area. As temperature primarily explains variations in electricity demand, we collect data on weather variations in areas with high electricity consumption. Using this reasoning, we average the data obtained from three weather stations with hourly data for each bidding area, either in or as close as possible to populous municipalities, including Luleå, Sundsvall, Stockholm, and Malmö.

We also gather data on coal prices. Most coal is traded on the international market and shipped by

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[2] The price data is obtained from Nord Pool's FTP server, which can be accessed by students without cost

sea, and the three major ports that receive coal for the European market are located in Amsterdam, Rotterdam, and Antwerp. Together, these are known as ARA ports, and we gather the daily ARA coal price futures in USD from Investing.com (2023). The weekly data on water inflow is collected from Swedenergy[3], a Swedish industry organization of nearly 400 electricity producers, distributors, and traders. The water inflow is measured in the corresponding GWh that the water can generate and is only available on a national level. Finally, the monthly data on production value index (PVI) is provided by Statistics Sweden (SCB). The lack of hourly data on all control variables lowers the variation in the data and may weaken our ability to entirely reduce hourly levels of omitted variable bias. However, due to the length of our time series, there is still sufficient variation in each variable to draw robust and precise conclusions.

The data covers the period from January 1, 2018, to December 31, 2021. The subsequent year, 2022, is a considerable outlier in terms of the overall price level and volatility, and the market characteristics differ significantly in many ways from prior years. We cannot account for all supply- and demand-side factors in 2022, including the war in Ukraine, elevated inflation, and associated initiatives to reduce electricity consumption. Extending the period backward yields results that are in line with ours.

## 6.2 Bidding Areas

We merge the northern and southern price areas into one area each, respectively, as proposed by Lundin (2022). Sweden was initially proposed to have two bidding areas compared to the ensuing four, with the dividing line precisely on the current separation between SE2 and SE3 (EI, 2007). The prices for the four bidding areas are visualized in Figure 4.

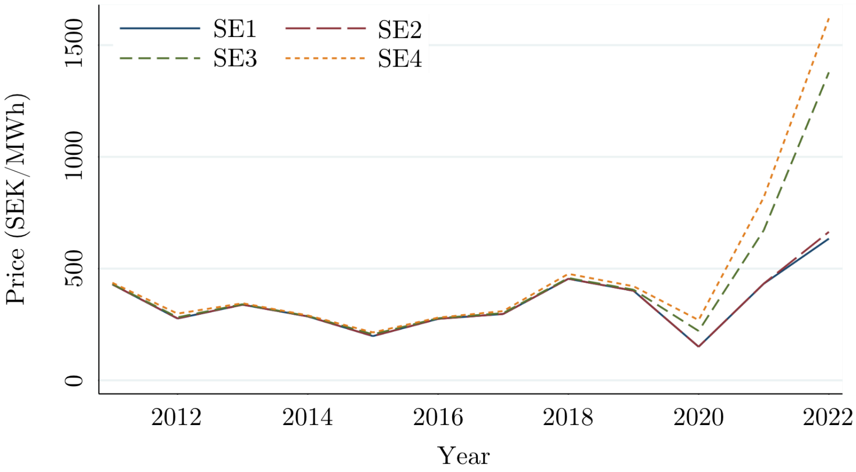

Figure 4: Average electricity price per bidding area

**Note:** This figure illustrates the average yearly wholesale electricity spot prices for the four Swedish bidding areas from January 1, 2011, to December 31, 2022. From 2011-2022, bidding zones SE1 and SE2 had on average 72% of the mean price in SE4, while SE3 had 91% of the mean price in SE4.

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[3] Historical data on water inflow can be obtained by contacting Swedenergy

The areas form a distinct pattern of groups: one for the two northernmost areas and one for the southernmost areas. The grouping is expected due to the similarity in characteristics for the areas with surplus production in the northern areas (SE1 and SE2) and electricity deficit in the southern areas (SE3 and SE4). Electricity prices were similar for all bidding areas until 2019 and have since diverged. The deviation can be attributed to elevated levels of water inflow in SE1 and SE2, the termination of nuclear reactor Ringhals 2 in SE3, and more extensive exports from SE3 and SE4 due to heightened prices in the fossil-dependent Baltics and Denmark (Lundin, 2022). Due to the price similarity within groups, we aggregate bidding areas 1 and 2 to form the single area north and likewise for areas 3 and 4, denoted south. By aggregating the four bidding areas into two, we gain simplicity without forfeiting ground for analysis.

Prices for the merged areas are weighted according to the electricity production in each of the areas. We follow the same procedure for each hour in the sample. Since prices are relatively homogenous within the merged zones, weighting the price on electricity consumption instead of production yields similar results. Following the same method, temperatures are weighted on consumption to represent demand accordingly, while the electricity production sources are summarized.

## 6.3 Summary Statistics

We clean the data as follows. Firstly, we have revised the electricity price data from Nord Pool to account for daylight saving time changes by altering it to the same format as production data from SVK. For the spring, when the clock is forwarded one hour, we collect the price for the hour prior to the change. For the autumn, when the clock is set back one hour, we only include the price for the first duplicated hour. Secondly, there are 27 instances of negative electricity prices for the northern area and 21 for the southern area. While it may appear surprising, negative prices are natural due to the constant need for balance in the system. Furthermore, it is becoming more common as it primarily materializes during the combination of low demand and high wind power production (Seel et al., 2021). Even though these observations do not constitute measurement errors, we replace them to enable the logarithmic transformation of the data. The observations are replaced with the last non-negative price prior to the price dipping below zero. Thirdly, the coal price data is based on daily futures, which are only traded during weekdays. Therefore, we extend Friday's price to also cover weekends, and the same method is applied to holiday periods.

The production data from SVK also includes solar power and unspecified electricity generation, as seen in Table 2. However, these production sources are negligible due to their nominal quantity, corresponding to 0.24% and 0.18% of the total supply. Therefore, they are not included in the final dataset.

Table 1: Summary Statistics

| Variable | Unit | Parameter | N | Mean | Std. Dev. | min | max | Median |
|---|---|---|---|---|---|---|---|---|
| Price north | SEK | | 35064 | 359.5 | 216.58 | .1 | 3711.24 | 378.87 |
| Price south | SEK | | 35064 | 451.32 | 372.08 | .1 | 6458.81 | 412.09 |
| Wind north | MWh | $\beta_1$ | 35064 | 1317.03 | 1111.48 | .84 | 5833.23 | 999.96 |
| Wind south | MWh | $\beta_2$ | 35064 | 1296.73 | 912.21 | 3.83 | 4392.32 | 1092.86 |
| Nuclear south | MWh | $\beta_3$ | 35064 | 6537.85 | 1442.53 | 2255.88 | 8671.27 | 6881.28 |
| Inflow | GWh | $\beta_4$ | 35064 | 1311.77 | 1148.95 | 270.1 | 7125.5 | 936.7 |
| Coal | USD | $\beta_5$ | 35064 | 80.82 | 37.71 | 38.6 | 274 | 69 |
| PVI | Index | $\beta_6$ | 35064 | 113.41 | 3.45 | 103.7 | 120.6 | 114.1 |
| Temp north | Celsius | $\beta_7$ | 35064 | 3.1 | 9.74 | -27.04 | 28.75 | 2.98 |
| Temp south | Celsius | $\beta_8$ | 35064 | 8.46 | 7.34 | -12.58 | 30.56 | 7.87 |
| Hydro north | MWh | | 35064 | 6460.13 | 2064.66 | 960.7 | 11073.67 | 6691.06 |
| Hydro south | MWh | | 35064 | 1312.66 | 507.99 | 262.21 | 2362.57 | 1326.21 |
| Thermal north | MWh | | 35064 | 138.67 | 62.78 | 9.19 | 304.39 | 130.43 |
| Thermal south | MWh | | 35064 | 712.43 | 404.82 | 138.32 | 2006.95 | 646.5 |

**Note:** This table presents the mean, standard deviation, minimum, maximum, and median values for the regression variables. Prices are measured in SEK per MWh, production units are measured per hour, and water inflow per week. The entire sample consists of 35064 observations from January 1, 2018, to December 31, 2021.

Table 2: Swedish electricity generation distribution by production source

| Production source | Production share |
|---|---|
| nuclear south | 36.63% |
| hydro south | 36.19% |
| wind north | 7.38% |
| hydro north | 7.35% |
| wind south | 7.26% |
| thermal south | 3.99% |
| thermal north | 0.78% |
| solar south | 0.23% |
| unspecified south | 0.18% |
| solar north | 0.01% |
| unspecified north | 0.00% |

**Note:** This table presents the distribution of electricity generation by production source in Sweden from January 1, 2018, to December 31, 2021. Production values in bidding areas SE1 and SE2 have been summed to form the aggregated northern area, and the production values in SE3 and SE4 have been summed to form the aggregated southern area.

# 7 Results

## 7.1 Merit Order Effect

We present the estimated results from Equation (22) in Table 3. The dependent variable is the wholesale electricity price (SEK/MWh) in the northern zone for columns (1)-(3) and in the southern zone for columns (4)-(6).

We present level-level specifications to attain results that correspond to what real-life wind power investors consider in investment decisions. This form of specification with changes in absolute price translates well into the core profitability framework. To achieve additional comparability with other studies, we also present a log-log specification in Appendix section B, which aligns with the results presented in this section. The standard errors are clustered at the daily level to account for within-cluster correlation due to the simultaneous clearance of all 24 hours of a day in the Elspot auction. Appendix section B contains supplementary Newey-West estimations with autocorrelation-consistent standard errors, confirming the results.

Table 3: Main Specification for the Northern (SE1 + SE2) and Southern (SE3 + SE4) Areas

|  | Parameter | (1) North | (2) North | (3) North | (4) South | (5) South | (6) South |
|---|---|---|---|---|---|---|---|
| Wind north | $\beta_1$ | -0.0419$^{***}$ | -0.0418$^{***}$ | -0.0459$^{***}$ | -0.0135$^{**}$ | -0.0149$^{**}$ | -0.0207$^{***}$ |
|  |  | (0.00428) | (0.00450) | (0.00465) | (0.00677) | (0.00686) | (0.00738) |
| Wind south | $\beta_2$ | -0.0230$^{***}$ | -0.0218$^{***}$ | -0.0250$^{***}$ | -0.0753$^{***}$ | -0.0760$^{***}$ | -0.0846$^{***}$ |
|  |  | (0.00354) | (0.00392) | (0.00372) | (0.00606) | (0.00684) | (0.00816) |
| Nuclear | $\beta_3$ | -0.0210$^{***}$ | -0.0254$^{***}$ | -0.0419$^{***}$ | -0.0124$^{**}$ | -0.0279$^{***}$ | -0.0621$^{***}$ |
|  |  | (0.00446) | (0.00387) | (0.00343) | (0.00622) | (0.00595) | (0.00544) |
| Inflow | $\beta_4$ | -0.0363$^{***}$ | -0.0352$^{***}$ | -0.0388$^{***}$ | -0.0196$^{***}$ | -0.0241$^{***}$ | -0.0300$^{***}$ |
|  |  | (0.00290) | (0.00299) | (0.00244) | (0.00459) | (0.00432) | (0.00386) |
| Coal | $\beta_5$ | 0.388$^{**}$ | 0.331$^{*}$ | 0.341$^{*}$ | 3.198$^{***}$ | 3.155$^{***}$ | 3.031$^{***}$ |
|  |  | (0.167) | (0.173) | (0.188) | (0.295) | (0.304) | (0.341) |
| PVI | $\beta_6$ | 14.77$^{***}$ | 15.31$^{***}$ | 16.42$^{***}$ | 21.58$^{***}$ | 22.05$^{***}$ | 31.06$^{***}$ |
|  |  | (1.683) | (1.864) | (1.980) | (2.700) | (2.759) | (3.591) |
| Temp north | $\beta_7$ | -2.912$^{***}$ | -2.881$^{***}$ | -1.977$^{**}$ | -7.649$^{***}$ | -6.988$^{***}$ | -3.919$^{**}$ |
|  |  | (1.059) | (1.071) | (0.919) | (2.389) | (2.425) | (1.975) |
| Temp south | $\beta_8$ | -4.959$^{***}$ | -6.284$^{***}$ | -2.720$^{**}$ | -12.77$^{***}$ | -12.78$^{***}$ | -9.227$^{***}$ |
|  |  | (1.226) | (1.431) | (1.159) | (1.848) | (2.070) | (1.992) |
| N |  | 35064 | 35064 | 35064 | 35064 | 35064 | 35064 |
| Week FE |  | Yes | No | No | Yes | No | No |
| Month FE |  | Yes | Yes | No | Yes | Yes | No |
| Clustered SE |  | Yes | Yes | Yes | Yes | Yes | Yes |

Dependent variable: Hourly Wholesale Electricity Price
Cluster-robust standard errors in parentheses
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

**Note:** This table presents the results of regressing the electricity price (SEK/MWh) on wind power generation and a set of controls. The dependent variable in columns (1)-(3) is the northern price, and in columns (4)-(6) is the southern price. All specifications are subject to time fixed effects at yearly, day-of-the-week, and hour-of-the-day level. Temperatures are measured in degrees Celsius, coal price in USD, and PVI is indexed production value. Water inflow is measured in GWh per week and all actual production parameters in MWh.

These results find the expected short-term merit effect to hold for both the northern and southern areas: additional wind production decreases the price of electricity. The parameters of interest are $\beta_1$ and $\beta_2$, representing the price effect of an additional MWh of electricity produced by wind power. Columns (1) and (4) are the main specifications with all fixed effects.

Our primary results in column (1) presents the price impact in the northern bidding zone. An additional MWh produced by wind power in the north is associated with a price decrease of 0.042 SEK per MWh, while an additional MWh of wind power in the south is related to a price reduction of 0.023 SEK per MWh. The price impact of additional wind power production is more substantial for generation in the local area compared to additional production in the non-local area.

We find similar results for the southern bidding zone in column (4). An additional MWh of wind power in the north is associated with a price reduction of 0.014 SEK per MWh, while an additional MWh of wind power in the south relates to a price reduction of 0.075 SEK per MWh. As in the north, the price effect is more prominent for increased local production.

The coefficients $\beta_1$ and $\beta_2$ show the relative sensitivities in profitability between the zones. A firm making an investment in the south is more sensitive to how much they own of the production in the north – than a firm making an investment in the north will be of how much it owns in the south. An intuitive explanation for why the coefficients differ between the areas relates to the differences in average prices between the two regions. Because the prices tend to be higher in the south than in the north, the area is more sensitive to changes in wind power production due to the merit order effect. Each additional unit of wind power, with a very low marginal cost, will replace a more expensive unit in the south than in the north, on average.

The coefficients for nuclear power, water inflow, and temperatures are negative. These results are in line with what was expected from the current literature and expressed in Empirical Method section 5.2. Lower temperatures increase the overall electricity demand, and when low-cost electricity generation sources can not cover all demand, high-cost conventional production sources enter the merit curve, elevating the marginal price. One factor of this relation can be seen in the positive coal price coefficients for both areas. We also note that the production value index has a positive relation to electricity price, which may be expected due to the relationship between the industrial activity and demand growth.

## 7.2 Profitability Framework

### 7.2.1 Empirical Findings

The core profitability framework function in Equation (15) presents the profitability implications of a firm that is subject to an expansion of wind power. In this section, the foundational assumption is that firms set their production levels independently, as in a short-run analysis. Thus, $J = 0$ . In the analysis, this assumption will be relaxed. As a reminder, the core profitability framework in Equation (15) is specified as follows:

$$\begin{aligned}
\triangle Profit_{firm} = \; & + I(Price_{local} + MOE_{local} I - VC) \\
& + (I + J)(share_{local} MP_{local} MOE_{local}) \\
& + (I + J)(share_{non-local} MP_{non-local} MOE_{non-local}) \\
& - FC
\end{aligned}$$

Using the framework, we form one function for each zone, which are populated as follows. The price ($Price_{local}$) is the average wholesale electricity price for each area, gathered from the data. Likewise, the hourly mean of total market production for each bidding area ($MP_{local}$ and $MP_{non-local}$) is obtained from the data. The variables for the merit order effect ($MOE_{local}$ and $MOE_{non-local}$) are populated by the coefficients for wind power production obtained from regressing the specification in Equation (22) for each area. Lastly, capture rates are also introduced explicitly, to account for the fact that the actual price earned can deviate from the average price, as was presented in Section 2.3.3. We use a capture rate of 85%, which is between the current rate and the forecasted future rate by Sweco (2023). Altogether, we derive the following marginal profit function for investments made in the north and south, respectively:

Change in profitability from a marginal wind power production increase in the north:

$$\begin{aligned}\triangle Profit_{firm} = & + ([359.5 - 0.0419] * \text{Capture Rate} - VC) \\ & + (share_{north} 7918.5 * (-0.0419)) \\ & + (share_{south} 9931.5 * (-0.0229)) \\ & - FC\end{aligned} \tag{23}$$

Change in profitability from a marginal wind power production increase in the south:

$$\begin{aligned}\triangle Profit_{firm} = & + ([451.3 - 0.0753] * \text{Capture Rate} - VC) \\ & + (share_{north} 7918.5 * (-0.0135)) \\ & + (share_{south} 9931.5 * (-0.0753)) \\ & - FC\end{aligned} \tag{24}$$

Thus, using the results from the regressions, we estimate the core profitability framework for a marginal investment in each respective area under the simplifying assumption that $J = 0$.

### 7.2.2 Profitability Cutoff Function

Using the firm profitability functions for each region, we investigate how incentives shift with market shares along a cutoff where profits turn to losses on an hourly basis. The profitability functions are set to zero and only encompass a marginal increase in wind power generation ($I = 1$). Fixed investment costs vary significantly across projects and firms, and are therefore not included in this illustration. In Figure 5 and 6, we present three different cases graphically:

1. A no-cost, base-case analysis. This scenario includes a capture rate of 100% and does not consider variable or fixed investment costs. The right-most red line represents this scenario.
2. A no-cost, capture-adjusted analysis. Represented by the semi-dotted line in the center, the second scenario encompasses a capture rate of 85%. While capture rates depend on the time of year and can vary geographically, this numeric value is expected to be a representative example.
3. A variable-cost, capture-adjusted analysis. Represented by the left-most dotted line, this scenario incorporates a capture rate of 85% and an average hourly variable cost associated with onshore wind farms of 20 SEK per MWh, as covered in Section 2.4.2.

Setting to zero and rearranging terms in Equation (23) for the northern region:

$$Share_{south} = \frac{(359.4 * \text{Capture Rate} - VC)}{228.2} - 1.45 * Share_{north} \tag{25}$$

Setting to zero and rearranging terms in Equation (24) for the southern region:

$$Share_{north} = \frac{(451.2 * \text{Capture Rate} - VC)}{107.1} - 6.99 * Share_{south} \tag{26}$$

Graphing Equation (25) and 26 illustrates the following investment incentive patterns depending on market shares for each area:

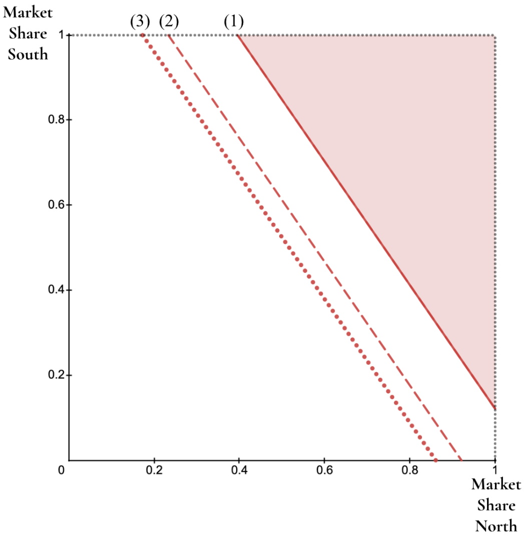


Figure 5: Profitability cutoff north

**Note:** The graph demonstrates the short-term relationships between marginal wind power investments in the north, regional market shares, and profitability. The horizontal x-axis represents the market share of the area where the investment is made (north) and the vertical y-axis shows the market share in the other area (south). The red lines represent the combination of market shares that makes the additional MWh wind power production unprofitable.

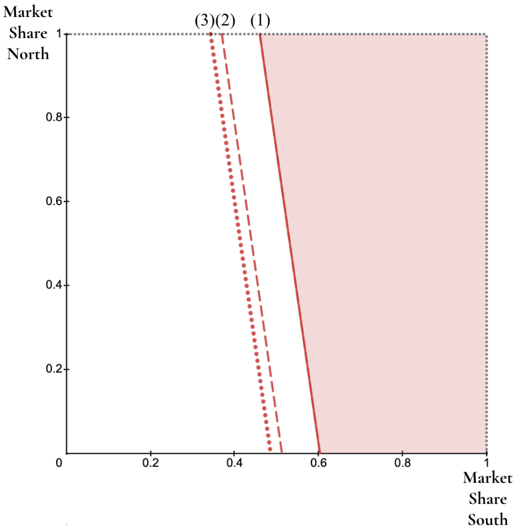


Figure 6: Profitability cutoff south

**Note:** The graph demonstrates the short-term relationships between marginal wind power investments in the south, regional market shares, and profitability. The horizontal x-axis represents the market share of the area where the investment is made (south) and the vertical y-axis shows the market share in the other area (north). The red lines represent the combination of market shares that makes the additional MWh wind power unprofitable.

The red lines represent the combination of market shares that makes the additional MWh wind power production unprofitable, with varying assumptions of capture rate and variable costs. The base case, without capture rate deviations or variable costs, is represented by the full red lines (1). Lines (2) and (3) respectively show the inclusion of an 85% capture rate as well as both a capture rate and an average hourly variable cost. If we were to model offshore wind farms or add the fixed investment costs, the higher costs would shift the dotted line further to the left.

Three distinct observations can be noted from these results. Firstly, these graphs demonstrate that an additional investment into wind power is less likely to be profitable for a firm the larger the firm's share of the electricity production in either zone. These results follow what was expected and expressed in the Model section 4.3.1.

Secondly, the change in hourly profitability clearly depends on where additional output of wind power generation is produced. The cut-off curves differ in terms of both position and slope depending on if an investment is made in the north or in the south. The relative steepness of the curves indicates that local market shares are more impactful for profitability than non-local market shares. The cutoff line is steeper in the southern parts of Sweden. This relates to the difference in local and non-local effects between the north and the south – ultimately indicating that the degree of local ownership is particularly important in the south.

Thirdly, capture rates greatly impact the intercept for the profitability cutoff lines. In this case, an 85% capture rate has been used, thus assuming that the average wholesale electricity price exceeds what wind projects earn on average. This effect varies depending on multiple factors and may change over time due to an expansion of demand response, see Section 2.3.3.

These results reveal several key relationships between wind power production, short-term wholesale electricity price, and the role of regional market shares in determining profitability. Increases in both local and non-local wind power production are associated with decreases in average wholesale electricity prices. Moreover, the core profitability framework demonstrates that differences in regional ownership may also lead to differences in investment incentives, as illustrated by the profitability cutoffs (1), (2), and (3).

# 8 Analysis

## 8.1 Short-run Implications

Together, these results can improve our understanding of:

1. To what extent do incumbent electricity-generating firms face diminishing incentives to expand wind power production due to market share effects, compared to domestic and foreign entrants?
2. Do these potential changes in incentives fully explain the investment patterns of foreign and domestic firms?

In a short-run analysis, we assume that firms consider other firms' wind power production levels as fixed, with $J = 0$ in Equation (15). In that scenario, companies with a larger share of the total electricity production will be less likely to invest in wind power. The larger the current electricity production of a firm, the more consequential the loss in revenue will be from the merit order effect. Additionally, the incentives to invest in wind power depend on their relative production ownership within the north or south regions. Our research in Section 7.2.2 suggests that firms may be particularly sensitive to pre-existing production when making investments in the south, as the shaded red area in Figure 6 is larger than in Figure 5.

Along similar logic, new entrants – without any current production in Sweden – will stand to gain the most, to the peril of incumbents. Upon investing, new entrants will earn revenues and face variable and fixed costs. In contrast to incumbent firms, they will not suffer the merit order effect on pre-existing production, which distinctly sets them apart.

The results of the core profitability framework indicate that entrants should have more considerable incentives to invest than incumbents in a short-run analysis. Nonetheless, the framework does not differentiate between foreign and domestic entrants or provide a nuance of the profit elements. In the next section, we extend the core profitability model. With references to the literature, we illustrate how differences in factors such as capital costs can lead to disparities in outcomes across foreign and domestic entrants.

## 8.2 Differences across Entrants

The current literature provides several nuances to the results from the core profitability framework. Empirical research brings forth that political decisions play a prominent role in why and where firms choose to invest in wind power production. Lundin (2022) finds that the market splitting reform in 2011 led to a shift in the location of Swedish wind power investments, while Mokhtari and Yen (2021) show that wind speed deviations – which determine wind power production in the short run – do not fully explain why firms invest where they do.

Furthermore, feed-in tariffs that shift incentives through pricing effects have also proven to be impactful (Couture and Gagnon, 2010b; Lauber, 2004; Rowlands, 2005). Similarly, the Swedish electricity certificate system has also affected production incentives through the phased-out RSP scheme. Together, these factors show that government decisions and incentives can play a role that has not been fully accounted for in the model.

Empirical research also highlights several critical dimensions that specifically influence foreign investment decisions in wind power generation. Hanni et al. (2011) observe that the most critical investment aspects are FDI entry criteria, long-term renewable electricity usage targets, and electricity market regulation. Moreover, accumulated experience is also a crucial factor for foreign entrants, and they conclude that early application of renewable energy commitments could help explain investments in Europe specifically. Thus, other factors than the possible direct price and marginal revenue effects matter indirectly to foreign firms.

Similarly, LV and Spigarelli (2016) present multiple qualitative host country factors to explain the determinants of Chinese renewable energy FDI. These factors may help explain, for example, why the Chinese firm CGN has been an aggressive foreign entrant in Swedish wind power production. Moreover, foreign investments may also influence the Swedish production environment through innovation, technology transfer, and other spillover effects – which may reduce costs for both incumbents and entrants (Atallah, 2007; Batten and Vo, 2009).

The core profitability framework presented in Section 4.3 considers capture rates, variable costs, and fixed investment costs. In reality, many factors influence these variables, and both variable and fixed investment costs may be extended to include aspects such as capital costs or transaction costs. Capital return requirements are also likely to be essential in determining which firms invest in wind power in Sweden (Energiforsk, 2021; Sweco, 2016). Firms with lower capital return requirements and access to capital with lower costs are predicted to be the ones expanding wind power production. Moreover, the current literature also indicates that foreign firms may face additional, unique transaction costs upon making energy investments. These include costs related to research and information gathering, negotiation and decision-making, as well as monitoring, language, and enforcing barriers (Wink Junior et al., 2011; Oh et al., 2011).

While all of these factors may matter for firms when making investment decisions, only a few are explicitly taken into account by the main profitability framework. In a short-term analysis where firms choose production independently of other firms ($J = 0$), the following components enter the investment decision:

Table 4: Overview of the implications by the core profitability framework on incumbent firms

| General Framework Implications | |
|---|---|
| △Profit Elements | Incumbent |
| Revenue Increase | $I(Price_{local} + MOE_{local}I - VC)$ |
| Revenue Decrease | $(I + J)(share_{local}MP_{local}MOE_{local})$ |
| | $(I + J)(share_{non-local}MP_{non-local}MOE_{non-local})$ |
| Fixed costs (h) | $FC$ |

Table 5: Overview of the implications by the core profitability framework on entrants

| General Framework Implications | |
|---|---|
| △Profit Elements | Entrant |
| Revenue Increase | $I(Price_{local} + MOE_{local}I - VC)$ |
| Revenue Decrease | |
| Fixed costs (h) | $FC$ |

All firms, regardless of their market presence or origin, yield new revenues if they produce additional wind power and sell this output on the energy market. Additional units of wind power production, independent of location, reduce the average price both locally and non-locally for all electricity produced. This merit order effect reduces the revenue of the incumbent firm's pre-existing production, while the entrant is unaffected. Furthermore, all firms have to pay fixed costs associated with the additional units of output.

The results from the profitability cutoff graphs in Section 7.2.2, are based on homogenous capture prices and variable costs of 20 SEK/MWh. Below, we nuance and extend the variable cost ($VC$) and fixed investment cost ($FC$) parameters. In this extended framework, these cost parameters are conditional on firm-type and explicitly include other factors commonly referenced in the literature:

Table 6: A detailed breakdown of implications conditional on firm type

| Other Potential Factors | | | |
|---|---|---|---|
| △Profit Elements | Incumbent | Domestic Entrant | Foreign Entrant |
| Foreign Transaction Costs | | | $-T$ |
| Financing Costs (h) | $-Fin_{Incumbent}$ | $-Fin_{Domestic}$ | $-Fin_{Foreign}$ |
| Accumulated Experience | +A | | +A |

Foreign firms face foreign-specific transaction costs, $T$. Moreover, the literature highlights that foreign entrants may be able to leverage accumulated experience from foreign operations, $A$, and we theorize that incumbent firms may also have such advantages. Experience is assumed to have a positive effect on the profitability of operations. Finally, all firms have to consider capital costs and capital return requirements. As a matter of simplification, we denote these as $Fin_{Incumbent}$, $Fin_{Domestic}$, and $Fin_{Foreign}$ to highlight potential differences in average costs across different firms.

Without considering accumulated experience, we note that foreign entrants will dominate domestic entrants as long as the sum of foreign transaction costs and foreign financing costs are lower than the sum of domestic financing costs:

$$T + Fin_{Foreign} < Fin_{Domestic} \iff T < Fin_{Domestic} - Fin_{Foreign} \tag{27}$$

The dynamic changes under the assumption that some foreign entrants enter with accumulated knowledge from home markets, or other forms of know-how which may benefit them in their operations that domestic entrants do not have. The value of this experience will decrease the costs associated with entry – the lack of such experience can be seen as an indirect cost for entrants without it. Thus, foreign firms will dominate domestic entrants if the difference between foreign transaction costs and experience utilization is lower than the difference in financing costs between domestic and foreign firms.

$$T + Fin_{Foreign} - A < Fin_{Domestic} \iff T - A < Fin_{Domestic} - Fin_{Foreign} \tag{28}$$

Differences in these components may help explain why 85% of investments into wind power generation between 2017 and 2024 are made by foreign firms. Incumbent firms, on the other hand, are affected in slightly different ways. Of the factors included in the extended framework in Section 8.2, incumbent firms benefit from accumulated experience and otherwise face the same costs as domestic entrants. Therefore, the relation between accumulated experience and the loss of revenue from pre-existing production determines the profitability ratio between the two types of firms. Assuming that the value of experience for an incumbent cannot exceed the absolute value of losses on current production, a large enough incumbent that only considers its own short-run profits would never invest in additional wind power.

All and all, the core profitability framework shows that sufficiently large incumbents are disincentivized to invest in wind power, while entrants without current production have more to gain. When exploring the cost elements further and contrasting the different firm types – we still find that large incumbent firms will not choose to invest. However, we observe that differences in these variables could help explain why foreign entrants may dominate domestic entrants in a short-run analysis.

Together, these frameworks provide us with an understanding of different firm incentives under the assumption that energy producers only consider their own actions, $J = 0$. This is a limited and simplified analysis in many regards. In the next section, we find that the investment patterns predicted by our framework under the current assumptions fail to explain why incumbents still invest in wind power generation.

## 8.3 Empirical Deviations from the Short-run Predictions

There are difficulties related to finding market shares for each Swedish bidding area, as neither the producers nor industry organizations tend to disclose such information. However, Swedenergy (2018) presented data on the largest electricity producers in Sweden until 2016. During that time, Vattenfall was the largest producer with 63.7 TWh production corresponding to 42% of total Swedish production, and the second largest producer had roughly 16% of the total production. We limit the scope to Vattenfall since they are by far the largest electricity producer.

Although they do not specify production per bidding zone, approximations can be made. All nuclear power generation is conducted in the southern area, and in 2016 Vattenfall had 55% of the national installed nuclear power capacity, corresponding to 33 TWh. Moreover, 80% of all hydropower capacity is located in the north, and Vattenfall had 49% of hydropower capacity, corresponding to 30 TWh. Under the assumption that their hydropower follows the general distribution, Vattenfall's nuclear and hydropower production in the north would be 24 TWh and 39 TWh in the south, without considering the residual 0.7 TWh production. These estimations correspond to a market share of 40% in the north and 41% in the south, resulting in significantly lower incentives to invest in wind power compared to an entrant, as presented in Appendix section C. In the southern zone, additional wind power investments are on the verge of being unprofitable, even before fixed costs are accounted for.

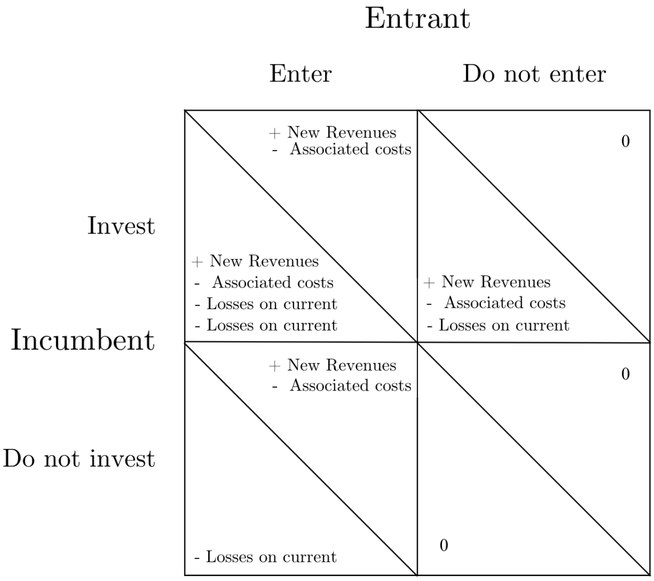
Yet, Vattenfall is still actively investing in wind power and is currently leading Nordic wind power expansion with Scandinavia's largest wind generator park, as covered in Section 2.4.1. Under the short-run assumption that $J = 0$ in the previous sections of the analysis, firms only consider whether or not their actions affect their own marginal profitability. The following two sections focus on how firm entry assumptions affect incumbent investment choices. Under the assumption that $J \geq 0$, we consider the case where incumbents analyze decisions long-term and also consider other firms' potential actions.

## 8.4 Long-run Explanations

### 8.4.1 If Incumbents Assume They Cannot Affect Entrant Decisions

If firms think long-term and consider the possibility of entry by other firms, such that the assumption that $J = 0$ is relaxed, dynamics shift. Suppose that incumbents cannot, or believe that they cannot, affect the behaviors of potential entrants through their actions. In that case, it will still never be a dominant strategy for a sufficiently large incumbent that is in proximity to the profitability cutoffs in Figure 5 or 6, to invest in wind power production. The reason is that if an incumbent firm is large enough, the losses on existing production outweigh the increase in revenue from more wind production, regardless of entrants.

This dynamic is illustrated in the following prisoner's dilemma game of Figure 7. Each firm decision is associated with a change in marginal profitability as described in the core profitability framework:



| Incumbent \ Entrant | Enter | Do not enter |
|---|---|---|
| Invest | + New Revenues<br>- Associated costs<br>+ New Revenues<br>- Associated costs<br>- Losses on current<br>- Losses on current | 0<br>+ New Revenues<br>- Associated costs<br>- Losses on current |
| Do not invest | + New Revenues<br>- Associated costs<br>- Losses on current | 0<br>0 |

Figure 7: Invest-entry matrix

**Note:** This figure illustrates an invest-entry prisoner's dilemma game between an incumbent and an entrant firm. The figure highlights how total payoffs depend on the choices of each respective party.

Figure 7 contrasts the various decisions and their payoffs for different firm types depending on their actions. If neither the incumbent nor the entrant chooses to invest, the status quo will be upheld, and the incumbent's profits will not be undercut. Suppose a new entrant expands into Swedish wind power production. The new entrant will obtain revenues, although at slightly lower prices if the incumbent decides to invest than if it does not invest, and the incumbent will face losses on existing production. Given that the incumbent firm acts like it cannot deter entry in this case, the incumbent's investment choice will only depend on its current market size:

1. If the incumbent firm is small enough to have new revenues from its own wind power expansion exceeding losses on current production and cover investment costs, they are incentivized to invest regardless of potential entrants.
2. If the incumbent firm is large enough, any additional revenues from increased incumbent production would be superseded by the corresponding losses on existing production. Accordingly, not investing would be the dominant strategy for the incumbents. This case is marked as dominant strategy one (DS1) in Figure 8 in the next section.

Ultimately, if an incumbent firm cannot influence potential entrants, their investment decision does not depend on whether or not $J = 0$ or $J > 0$. In that case, the long-term strategic choice is the same as the short-term analysis would predict. Neither case would see incumbent investments. In the next section, we show that this result changes if incumbents can, or believe that they can, affect entrant decisions.

### 8.4.2 If Incumbents Assume They Can Affect Entrant Decisions

Empirical research shows that many factors influence a firm's decision of whether to invest in renewable energy, not least an incumbent's ability to exercise credible deterrence towards potential entrants, as covered in Section 3.3. A potential reason for Vattenfall's continued wind power expansion could be if the investments are entry-deterring. Under the assumption that incumbent firms can, or believe that they can, deter new firms through overinvesting, it may be a dominant strategy. Then, an incumbent firm may choose to invest in wind power generation – even if a short-run analysis would predict such action to be unprofitable – if it deters new firms from entering in the long run. This scenario appears to overlap and align with the results by Meunier and Finon (2023) that suggest underinvestment in production strategies might not be a credible strategy in terms of deterrence. Figure 8 presents this entry deterrence as the dominant strategy two (DS2).

Such actions would only be motivated by sufficiently large incumbents, who would stand to lose more on new entrants in the long run than on conducting short-term tactics. If incumbents could, for example, attain permits for wind power in productive locations in specific regions, they could either prolong the construction process or, later, decide not to build altogether. Similarly, constructing low-capacity parks in highly productive locations could diminish the market size and attractiveness for foreign investors. Moreover, if incumbent firms invest in wind power, they may be able to yield power over potential entrants that look to invest in already-built projects. By controlling the supply of generators, and deciding which firms get to purchase what, they may be able to force potential entrants into cooperation. Analyzing whether entry-deterrence overinvestment occurs would require extensive research on each permit application to gather the capacity constraints and time frame of the investment. Since there is no such readily available granular data, it remains for future research.

In Figure 8, potential incumbent and entrant actions conditional on beliefs and capabilities are illustrated as follows:

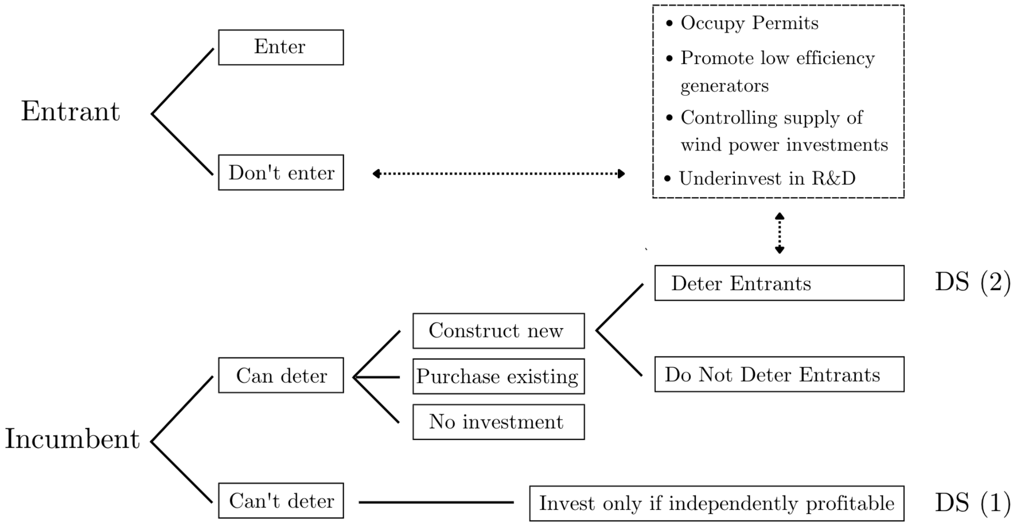


Figure 8: Decision strategy map

**Note:** This illustration shows two decision trees outlining incumbent and entrant decisions, as well as how they relate to each other. Incumbent strategies depend on whether or not deterrence is assumed to be possible, and two dominant strategies are marked DS (1) and DS (2).

In conclusion, a short-run analysis using the core profitability framework indicates that entrants may be more incentivized to invest in wind power than incumbents. When extending this analysis and allowing for variation in various cost components, we find conditions that would allow foreign entrants to dominate the market. However, data reveals that large incumbents still invest, which can be explained by long-run equilibrium dynamics. If it is assumed that incumbent firms can influence the decisions of potential entrants through their actions in the long run, choosing to invest might be a dominant strategy, even if it predicts short-term losses.

# 9 Discussion

The most reliable estimates for the merit order effect are given in column (1) and (4) of Table 3. The expected merit order effect is observed in all specifications, including robustness checks, and our results are thus aligned with existing literature (Gelabert et al., 2011; Gil et al., 2012; Macedo et al., 2021). Using these estimates, we answer the first research question by illustrating the extent to which incumbent firms face diminishing incentives with increased market shares. These findings form an extension to previous research on another dimension of wind power expansion, concluding that higher wind power penetration in an energy market is less adverse for investors with a higher wind-to-fossil production ratio (Mokhtari and Yen, 2021). To our knowledge, it is the first structural approach to quantify the regional-dependent profitability implications of an incumbent firm, and act as a vital foundation for understanding the rise of foreign ownership in the Swedish electricity market.

When allowing incumbent firms to assess and possibly deter market entrants, both domestic and foreign, more nuances arise. We identify assumptions and possible strategies of incumbent firm entry-deterrence, of which overinvesting can provide a complementary explanation to our second research question. These findings extend the results of existing literature on FDI and renewable energy, including various determinants of FDI and models of entry-deterrence (Oh et al., 2011; Hanni et al., 2011; LV and Spigarelli, 2016; Strandholm and Espinola-Arredondo, 2020). Our results indicate that the diminishing incentives do not fully explain the investment patterns of foreign and domestic firms. While it is not the aim of this paper to encompass all explanations of the investment patterns, in this section we aim to present alternative explanations to our findings, in addition to limitations, external validity, and policy implications.

## 9.1 Alternative Explanations

One of the alternative explanations for the significant increase in foreign investments is that foreign firms may have access to large amounts of low-cost capital required to build modern wind farms. Furthermore, by outsourcing the development and maintenance and reducing risks through long-term PPAs, foreign financial firms with a higher proportion of equity financing could contract a developer and subcontractor on the Swedish market, making the entry barriers less burdensome. If incumbent firms invest in wind power knowing this, they may be able to yield power over potential entrants that look to invest in already-built projects. Political aspects could also be part of the motives: a foreign investor could support the host country's energy targets to earn trust or to establish partnerships through energy diplomacy.

On a similar note, there are alternative explanations as to why the largest incumbent firm continues to invest in wind power despite being disincentivized to do so according to our findings. An incumbent could exercise market power to neutralize, or even exceed, the negative financial implications of the merit order effect. Market power could be exercised by strategic bidding of wind power (Ito and Reguant, 2016; Yu et al., 2023) and selectively managing hydropower water supply (Fridolfsson and Tangerås, 2008; Kauppi and Liski, 2008). Another, more long-term explanation, is that the expectation of increased demand response in the future will stabilize the electricity price during a full day, elevating the capture rate of wind and thereby making wind power generation more profitable. However, forecasts on reduced capture rate in the future limits the accuracy of this explanation Sweco (2023).

The investments could also be attributed to Vattenfall's directive to lead the transition to renewable energy production, but the bonus structure of their managers might imply otherwise, as covered in Section 2.3.1. Moreover, Vattenfall has production in several Nordic and European countries. This also complicates the dynamic, as they might be optimizing their investments on an international level in a way that the core framework used in this paper does not capture.

## 9.2 Limitations, External Validity, and Future Research

This paper is subject to several operational limitations. Firstly, temperature and PVI are not perfect controls for electricity demand in the price elasticity regression and could affect the quality of our findings. An alternative route could be constructing a forecasted demand, as proposed by Kim and Knittel (2006). Nevertheless, the forecasted demand is based primarily on weather forecasts and economic activity, and we thus believe our controls align fairly well. Moreover, improved controls, primarily within input resources to thermal power generation such as oil and natural gas prices, could possibly decrease omitted variable bias. However, as the relationship between these factors and wind generation should not have a significant correlation conditional on all other variables, this should not have a large effect.

We lack data on entry-deterring overinvestment behaviors and firm-level market share data per bidding area. Empirical observations on whether incumbent firms exercise overinvestment strategies would allow for an improved evaluation of the credibility of the procedure. It could act as a worthwhile topic for further investigation. Similarly, the lack of firm-level regional market shares makes it more complicated to test the predictions of our core profitability framework. It constrains our ability to answer the research question. However, we can gauge approximate market shares, and the lack of perfect data does not constrain the examination of factors that ultimately affect a foreign entrant's investment decision.

Another area where additional data could increase precision in the analysis regards the capture rate. As presented in the profitability cutoff functions in Section 7.2.2, different assumptions about the capture rate for wind power can have significant impacts on the results. Estimating the capture rate precisely and understanding how it may change over time as new technologies develop is an important future avenue of exploration.

Merging the four bidding areas into two entails limitations due to the price discrepancy between the two southernmost areas, primarily present during 2020 and 2021. There is little previous literature on the merit order effect and investment decisions at the bidding-area level. At some threshold, the price difference within the southern areas warrants a more granular analysis to ensure the result depicts reality to a satisfactory extent. Such analysis could be conducted using three or four bidding areas and is an avenue for future research.

Moreover, due to limited resources, the scope of this paper is restricted to the Swedish electricity market during 2018-2021. The subsequent year, 2022, is a considerable outlier in terms of the overall price level and volatility, and the market characteristics differ significantly from prior years in several ways. Because the scope is limited to Sweden, we do not include electricity supply or demand in other geographical markets. Including adjacent countries trading on Nord Pool would likely enhance the reliability of our results and make them more robust. Suitable markets for such an extension would include Denmark, Finland, Norway, and the Baltics.

This paper also has limitations regarding practical usability. Our regression model estimates the short-run effect of additional wind power. Wind power investments are, on the contrary, long-term by nature, with processes of multiple years, as covered in Section 2.4.1. Given the ambiguity of extrapolating the short-run merit order effect to the long-term, as described by Antweiler and Muesgens (2021), our results should be cautiously inferred for investment decisions. Even if a firm can circumvent the traditional procedure by acquiring an existing wind farm, the time frame would likely be measured in months. Furthermore, acquiring an operational wind farm would not increase total wind power production, and it is hence inconsequential concerning the profitability framework. Nevertheless, transactions of existing generators may likely play a larger role as the sector grows – and may thus make the market less comparable over time if such forms of investments affect incentives.

Furthermore, the profitability framework proposed in this paper is designed at the margin: one MWh increase in wind power production. It is reasonable to assume that there is a constraint on the amount of additional wind power production under which the framework holds. At some threshold, other parameters may enter the framework. As the Swedish energy sector transforms and wind generation levels increase, the merit order effect may change due to structural changes. Moreover, the framework considers whether investments may be profitable for a firm given the relative market shares that the firm currently holds in the north and the south of Sweden. This works well for smaller levels of investment. However, very large investments may not only have a merit order effect on the prices but could potentially also shift the relationship between new and existing production substantially. If such changes are of great magnitude, the core profitability framework might no longer be an appropriate model.

Our findings are dependent on the local electricity market dynamics, primarily in Sweden but also in the Nordics. Extrapolating our findings, either for the same market but at other points in time or other geographical markets, should be done with caution. Even though we draw conclusions based on the entire Swedish wind power production instead of a limited sample, such extrapolation should be done with care due to various dissimilarities between markets, even for other European countries using the same marginal price setting. Other significant parameters in which markets can differ include the electricity supply mix, demand patterns, price volatility, and entry barriers.

## 9.3 Policy Implications

This paper investigates how market ownership dynamics interact with investment incentives on the topic of wind power production. This area is of high policy relevance as the need for electricity is growing at a rapid rate in Sweden – and understanding how different mechanisms serve to increase or decrease the production of various sorts is crucial for government and industry. Our results indicate that regional firm market shares matter for the investment decision – at least in a short-term analysis – and that incumbent firms may employ deterrence tactics. Policymakers may use these findings when designing potential tax schemes, subsidies, or other incentive-related policies to ensure reaching renewable energy targets, foreign policy aspirations, or other goals. Understanding the beliefs and assumptions that drive firm decisions can be essential to properly designing political strategies and ensuring sound policies.

There may also be several practical lessons from our results. For example, legislators may be able to enhance incumbent firms' investment incentives by introducing a reimbursement system to counteract losses on pre-existing electricity production. The importance of capital costs can also be leveraged by introducing policies that increase access to low-cost, long-term financing, increasing the resilience of domestic firms. Furthermore, the value of accumulated experience and know-how was also highlighted. In this regard, our paper may shift focus towards assisting organizations that work within project development and the curating of new knowledge. Moreover, this paper may induce interest and inspire new conversations on the topic of the Swedish electricity market and its future – engaging consumers, politicians, and other stakeholders in the industry.

## 10 Conclusion

The Swedish electricity market has developed rapidly since the liberalization in 1996, and wind power has grown to account for almost 20% of the total Swedish production in only a few years. A substantial part of this growth has been driven by foreign firms, which has led to a high share of foreign ownership in the wind market. In this paper, we find that incumbent firms face diminishing incentives to invest into wind generation compared to both domestic and foreign entrants in a short-run analysis based on a core profitability framework. Differentiating between factors such as capital costs and the value of previous experience provides further explanations as to why foreign firms' investment may be prevalent. Under the short-run assumption that firms only think about their production independent of others, the results do not fully explain actual firm behaviors. We highlight this matter by investigating the investment pattern of the largest incumbent firm, Vattenfall, and its estimated local market shares. In a long-run equilibrium analysis, we show that incumbent investment choices depend on whether they can, or think that they can, affect entrant decisions through strategic deterrence in an entry-game context. Entry deterrence strategies, including overinvesting in suboptimal capacity or underinvesting in R&D may be a dominant strategy if it maximizes long-term profits, even though it may lead to short-term losses.

These results matter for several reasons. They highlight the role of ownership in investments and provide stakeholders with additional insight for analyzing, predicting, and managing the market. Mapping what firms are incentivized to invest where may help governing bodies gauge how elements ranging from transmission constraints to demand growth will shift over the coming decades. Furthermore, the findings help contribute to the discussions regarding foreign policy in the Swedish energy market. Chinese involvement in the Swedish wind power sector has been a topic of broad conversation, and our results help clarify that the emergence of foreign ownership may be explained, at least in part, by financial motivations.

Our paper also identifies several areas where the current literature can be extended in future papers. Our region-varying analysis using an estimated merit order effect may not hold as the energy sector transforms in the long term. How the dynamics are expected to shift as the merit order effect changes over time is an area for future research. Moreover, we also identify that deterrence strategies might be employed by large Swedish incumbents, outside political motivations. Previous literature has found that electricity-generating incumbent firms are seldom able to deter entry through reduced production. We theorize that overproduction may be an opposite strategy used. To what extent overinvesting – or other tactics such as permit process stalling, supply control, or capacity capping through low-capacity generators – is used, is another area for future exploration. Novel research may also want to analyze the effects of major recent events such as the Ukraine war, global recession, and inflation concerns as well as COVID-19.

The Swedish energy market is expected to grow at a tremendous rate over the coming decades to meet increasing demand from industry and private consumption. Where this energy comes from and who produces it is of national interest. While this paper shows how investment incentives into wind energy shift depending on inter-regional ownership structures, it raises even more questions. As the debate grows and interest in the evolving wind power market builds, more and more research will be needed to facilitate a sustainable shift towards green, renewable energy.

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# Appendices

## A Regression Method

We estimate the quantity supplied for a given hour using data on wind and nuclear power production, water inflow, and coal prices while controlling for temperatures and time fixed effects:

$$\begin{aligned} Q_S = &+ b_0 + b_1 wind_{north} + b_2 windsouth + b_3 nuclear + b_4 inflow + b_5 P_{coal} + b_6 P_e \\ &+ b_7 temp_{north} + b_8 temp_{south} + b_9 year + b_{10} month + b_{11} week + b_{12} dayofweek \\ &+ b_{13} hour + \epsilon_D \end{aligned} \tag{29}$$

Similarly, we assume that the quantity demanded for a given hour can be estimated with hourly data on temperatures and monthly production value index data, conditional on time fixed effects:

$$\begin{aligned} Q_D = &+ a_0 + a_1 temp_{north} + a_2 temp_{south} + a_3 PVIndex + a_4 P_e + a_5 year + a_6 month \\ &+ a_7 week + a_8 dayofweek + a_9 hour + \epsilon_D \end{aligned} \tag{30}$$

The quantity supplied will equal the quantity demanded in equilibrium, rendering an electricity price equation that can be estimated using OLS. The price function can therefore be estimated by the following equation:

$$\begin{aligned} P_e = &+ \frac{1}{a_4 - b_6}[(b_0 - a_0) + b_1 wind_{north} + b_2 windsouth + b_3 nuclear + b_4 inflow \\ &+ b_5 P_{coal} + (b_7 - a_1) temp_{north} + (b_8 - a_2) temp_{south} + (-a_3) PVIndex \\ &+ (b_9 - a_5) year + (b_{10} - a_6) month + (b_{11} - a_7) week + (b_{12} - a_8) dayofweek \\ &+ (b_{13} - a_9) hour + (\epsilon_S + \epsilon_D] \end{aligned} \tag{31}$$

# B Supplementary Regression Specifications

In column (7), Table B.1 and B.2, the alternative regression estimation using actual production levels as variables is specified as:

$$\begin{aligned} P_{t,a} = & + \beta_0 + \beta_1 Wind_{t,north} + \beta_2 Wind_{t,south} + \beta_3 Nuclear_t + \beta_4 Hydro_{t,north} \\ & + \beta_5 Hydro_{t,south} + \beta_6 Thermal_{t,north} + \beta_7 Thermal_{t,south} + \beta_8 PVI_t \\ & + \beta_9 temp_{t,north} + \beta_{10} temp_{t,south} + \phi_Y + \psi_M + \omega_W + \theta_D + \kappa_H + \epsilon_{t,a} \end{aligned} \tag{32}$$

Table B.1: Supplementary estimated specifications for the northern bidding areas (SE1 + SE2)

| | Parameter | (1) Level-level | (2) Level-level | (3) Level-level | (4) Level-level | (5) Log-Log | (6) Log-Level | (7) Level-level |
|---|---|---|---|---|---|---|---|---|
| Wind north | $\beta_1$ | $-0.0419^{***}$ | $-0.0419^{***}$ | $-0.0419^{***}$ | $-0.0419^{***}$ | | $-0.000151^{***}$ | $-0.0327^{***}$ |
| | | (0.00104) | (0.00146) | (0.00258) | (0.00428) | | (0.0000113) | (0.00399) |
| Wind south | $\beta_2$ | $-0.0230^{***}$ | $-0.0230^{***}$ | $-0.0230^{***}$ | $-0.0230^{***}$ | | $-0.000133^{***}$ | $-0.0147^{***}$ |
| | | (0.000984) | (0.00137) | (0.00235) | (0.00352) | | (0.0000143) | (0.00377) |
| Nuclear south | $\beta_3$ | $-0.0210^{***}$ | $-0.0210^{***}$ | $-0.0210^{***}$ | $-0.0210^{***}$ | | $-0.0000394^{**}$ | $-0.00767^{*}$ |
| | | (0.00107) | (0.00150) | (0.00265) | (0.00441) | | (0.0000156) | (0.00441) |
| Water Inflow | $\beta_4$ | $-0.0363^{***}$ | $-0.0363^{***}$ | $-0.0363^{***}$ | $-0.0363^{***}$ | | $-0.000185^{***}$ | |
| | | (0.000778) | (0.00108) | (0.00183) | (0.00285) | | (0.0000151) | |
| Price Coal | $\beta_5$ | $0.388^{***}$ | $0.388^{***}$ | $0.388^{***}$ | $0.388^{**}$ | | -0.000820 | |
| | | (0.0375) | (0.0526) | (0.0947) | (0.168) | | (0.000535) | |
| PVI | $\beta_6$ | $14.77^{***}$ | $14.77^{***}$ | $14.77^{***}$ | $14.77^{***}$ | | $0.0705^{***}$ | $12.22^{***}$ |
| | | (0.398) | (0.556) | (0.988) | (1.671) | | (0.00508) | (1.333) |
| Temp north | $\beta_7$ | $-2.912^{***}$ | $-2.912^{***}$ | $-2.912^{***}$ | $-2.912^{***}$ | -0.0000371 | 0.00300 | $-1.909^{**}$ |
| | | (0.261) | (0.363) | (0.637) | (1.030) | (0.00259) | (0.00257) | (0.922) |
| Temp south | $\beta_8$ | $-4.959^{***}$ | $-4.959^{***}$ | $-4.959^{***}$ | $-4.959^{***}$ | $-0.0118^{***}$ | $-0.0143^{***}$ | 1.317 |
| | | (0.342) | (0.475) | (0.807) | (1.197) | (0.00349) | (0.00342) | (1.122) |
| Wind north (ln) | | | | | | $-0.103^{***}$ | | |
| | | | | | | (0.0102) | | |
| Wind south (ln) | | | | | | $-0.109^{***}$ | | |
| | | | | | | (0.0120) | | |
| Nuclear south (ln) | | | | | | $-0.198^{**}$ | | |
| | | | | | | (0.0881) | | |
| Water Inflow (ln) | | | | | | $-0.452^{***}$ | | |
| | | | | | | (0.0325) | | |
| Price Coal (ln) | | | | | | 0.00585 | | |
| | | | | | | (0.0581) | | |
| PVI (ln) | | | | | | $8.336^{***}$ | | |
| | | | | | | (0.610) | | |
| Hydro north | | | | | | | | $0.00878^{***}$ |
| | | | | | | | | (0.00237) |
| Hydro south | | | | | | | | $-0.0202^{*}$ |
| | | | | | | | | (0.0122) |
| Thermal north | | | | | | | | $0.589^{***}$ |
| | | | | | | | | (0.117) |
| Thermal south | | | | | | | | $0.231^{***}$ |
| | | | | | | | | (0.0353) |
| N | | 35064 | 35064 | 35064 | 35064 | 35064 | 35064 | 35064 |
| Week FE | | Yes | No | No | Yes | Yes | Yes | Yes |
| Month FE | | Yes | Yes | No | Yes | Yes | Yes | Yes |
| Clustered SE | | No | No | No | No | Yes | Yes | Yes |
| Lags | | 0 | 1 | 6 | 24 | 0 | 0 | 0 |

Dependent variable: wholesale electricity price in the northern zone
Robust standard errors in parentheses
$^{*}\ p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$

This table presents the results of regressing the electricity price (SEK/MWh) in the northern zone on wind power generation and a set of controls. Columns (1)-(4) are Newey-West estimations with varying lags. Column (5) and (6) is in logarithmic transformation. Column (7) is based on actual production of hydropower and thermal power. All specifications are subject to time fixed effects at yearly, day-of-the-week, and hour-of-the-day level. Temperatures are measured in degrees Celsius, coal price in USD, and PVI is indexed production value. Water inflow is measured in GWh per week and all actual production parameters in MWh.

Table B.2: Supplementary estimated specifications for the southern bidding areas (SE3 + SE4)

| | Parameter | (1) Level-level | (2) Level-level | (3) Level-level | (4) Level-level | (5) Log-Log | (6) Log-Level | (7) Level-level |
|---|---|---|---|---|---|---|---|---|
| Wind north | $\beta_1$ | -0.0135$^{***}$ | -0.0135$^{***}$ | -0.0135$^{***}$ | -0.0135$^{**}$ | | -0.0000741$^{***}$ | -0.00384 |
| | | (0.00193) | (0.00267) | (0.00452) | (0.00673) | | (0.0000113) | (0.00618) |
| Wind south | $\beta_2$ | -0.0753$^{***}$ | -0.0753$^{***}$ | -0.0753$^{***}$ | -0.0753$^{***}$ | | -0.000240$^{***}$ | -0.0585$^{***}$ |
| | | (0.00173) | (0.00240) | (0.00408) | (0.00610) | | (0.0000147) | (0.00592) |
| Nuclear south | $\beta_3$ | -0.0124$^{***}$ | -0.0124$^{***}$ | -0.0124$^{***}$ | -0.0124$^{**}$ | | -0.0000686$^{***}$ | 0.000253 |
| | | (0.00174) | (0.00241) | (0.00407) | (0.00618) | | (0.0000155) | (0.00633) |
| Water Inflow | $\beta_4$ | -0.0196$^{***}$ | -0.0196$^{***}$ | -0.0196$^{***}$ | -0.0196$^{***}$ | | -0.000136$^{***}$ | |
| | | (0.00122) | (0.00169) | (0.00288) | (0.00453) | | (0.0000167) | |
| Price Coal | $\beta_5$ | 3.198$^{***}$ | 3.198$^{***}$ | 3.198$^{***}$ | 3.198$^{***}$ | | 0.00290$^{***}$ | |
| | | (0.0810) | (0.112) | (0.188) | (0.296) | | (0.000511) | |
| PVI | $\beta_6$ | 21.58$^{***}$ | 21.58$^{***}$ | 21.58$^{***}$ | 21.58$^{***}$ | | 0.0665$^{***}$ | 20.37$^{***}$ |
| | | (0.689) | (0.962) | (1.674) | (2.699) | | (0.00525) | (2.408) |
| Temp north | $\beta_7$ | -7.649$^{***}$ | -7.649$^{***}$ | -7.649$^{***}$ | -7.649$^{***}$ | -0.00174 | -0.0000476 | -4.728$^{**}$ |
| | | (0.607) | (0.848) | (1.485) | (2.402) | (0.00258) | (0.00260) | (2.179) |
| Temp south | $\beta_8$ | -12.77$^{***}$ | -12.77$^{***}$ | -12.77$^{***}$ | -12.77$^{***}$ | -0.0244$^{***}$ | -0.0222$^{***}$ | 4.641$^{**}$ |
| | | (0.558) | (0.772) | (1.281) | (1.849) | (0.00361) | (0.00355) | (1.817) |
| Wind north (ln) | | | | | | -0.0508$^{***}$ | | |
| | | | | | | (0.00916) | | |
| Wind south (ln) | | | | | | -0.189$^{***}$ | | |
| | | | | | | (0.0126) | | |
| Nuclear south (ln) | | | | | | -0.317$^{***}$ | | |
| | | | | | | (0.0897) | | |
| Water Inflow (ln) | | | | | | -0.319$^{***}$ | | |
| | | | | | | (0.0341) | | |
| Price Coal (ln) | | | | | | 0.405$^{***}$ | | |
| | | | | | | (0.0548) | | |
| PVI (ln) | | | | | | 7.173$^{***}$ | | |
| | | | | | | (0.642) | | |
| Hydro north | | | | | | | | -0.0211$^{***}$ |
| | | | | | | | | (0.00380) |
| Hydro south | | | | | | | | 0.108$^{***}$ |
| | | | | | | | | (0.0146) |
| Thermal north | | | | | | | | 0.156 |
| | | | | | | | | (0.146) |
| Thermal south | | | | | | | | 0.846$^{***}$ |
| | | | | | | | | (0.0548) |
| N | | 35064 | 35064 | 35064 | 35064 | 35064 | 35064 | 35064 |
| Week FE | | Yes | No | No | Yes | Yes | Yes | Yes |
| Month FE | | Yes | Yes | No | Yes | Yes | Yes | Yes |
| Clustered SE | | No | No | No | No | Yes | Yes | Yes |
| Lags | | 0 | 1 | 6 | 24 | 0 | 0 | 0 |

Dependent variable: wholesale electricity price in the southern zone
Robust standard errors in parentheses
$^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

This table presents the results of regressing the electricity price (SEK/MWh) in the southern zone on wind power generation and a set of controls. Columns (1)-(4) are Newey-West estimations with varying lags. Column (5) and (6) is in logarithmic transformation. Column (7) is based on actual production of hydropower and thermal power. All specifications are subject to time fixed effects at yearly, day-of-the-week, and hour-of-the-day level. Temperatures are measured in degrees Celsius, coal price in USD, and PVI is indexed production value. Water inflow is measured in GWh per week and all actual production parameters in MWh.

# C Profitability Cutoff: The Case of Vattenfall

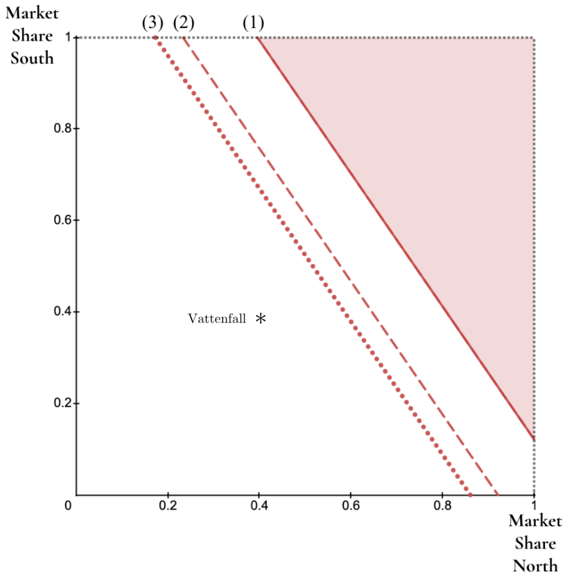

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Figure C.1: Vattenfall: Profit Cutoff North

**Note:** The graph demonstrate the short-term relationships between marginal investments in wind power in the north, market shares, and profitability, with Vattenfall's estimated relative shares marked with (*).

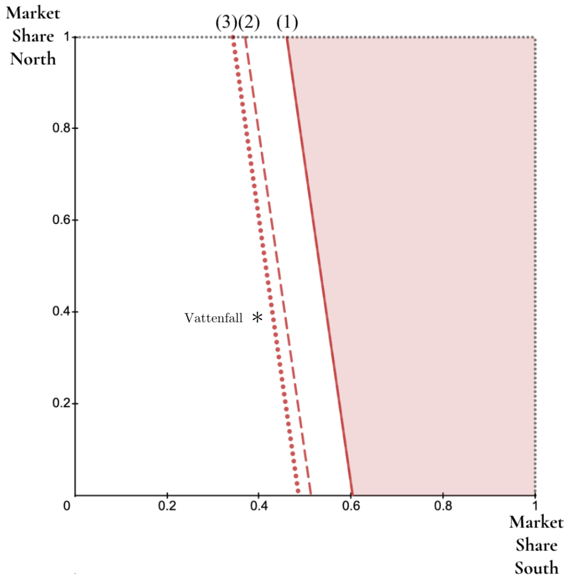

Figure C.2: Vattenfall: Profit Cutoff South

**Note:** The graph demonstrates the short-term relationships between marginal investments in wind power in the south, market shares, and profitability, with Vattenfall's estimated relative shares marked with (*).