CESifo WORKING PAPERS

11079
2024

April 2024

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CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
https://www.cesifo.org/en/wp
An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
· from the RePEc website: www.RePEc.org
· from the CESifo website: https://www.cesifo.org/en/wp

CESifo *Working Paper No. 11079*

Vertical Integration in Tradable Green Certificate Markets

Abstract

This study examines how the impact of Tradable Green Certificates (TGC) on profitability and investment behavior varies depending on the vertical integration status of regulated firms. Our theoretical model predicts that vertical integration does not lead to higher profits when internal pricing aligns with market values for green certificates. However, it stimulates greater investment in renewable electric capacity since it reduces the costs of the sourced certificates. Empirical analysis of the Swedish TGC system confirms these findings, revealing that vertically integrated firms did not experience profit increases. Instead, they exhibited distinct investment patterns, prioritizing cost-effective technologies like hydro and thermal capacity over more expensive renewables, in contrast to non-integrated firms.

JEL-Codes: L100, L500, Q580.

Keywords: renewable energy, tradable green certificates, vertical integration, firm-level data, causal effects, profits, investments, Sweden.

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April 14, 2024
Research funding from Handelsbanken’s Jan Wallander and the Tom Hedelius Research Foundation is gratefully acknowledged.

1 Introduction

In the past few decades, numerous countries have actively supported the generation of electricity from renewable energy sources (RES), such as hydro, wind, solar, and biomass. This commitment to renewable energy can be observed in various regions, including the European Union's (EU) member states, numerous states of the United States of America (U.S.), and Australia, where mandates exist to ensure that a proportion of the total energy supply is sourced from RES. For instance, the EU's Renewable Energy Directive sets a 32% renewable energy target for 2030. However, recent proposals suggest raising it to 42.5% or even 45% emphasizing the EU's commitment to renewable energy. In parallel, in the U.S., the Biden administration has announced a goal of achieving a carbon-free energy sector by 2035. Australia's renewable energy adoption has also been on the rise. Notably, the federal government has established an ambitious target of achieving 82% of renewable electricity generation by the year 2030. These objectives imply a substantial increase in the share of renewable energy in the overall energy mix.

To meet renewable energy goals, many countries have adopted a mechanism called Tradable Green Certificates (TGCs).[1] Under such a system, producers of electricity from renewable energy sources (RES-E) are given a tradable green certificate (TGC) for each megawatt-hour (MWh) of renewable electricity they produce and feed into the grid. This provides them with two streams of revenue: sales of electricity in the electricity market and sales of TGCs in the TGC market, which help RES-E producers recover the extra cost of production, compared to conventional electricity generation. In turn, electricity retailers are required to purchase a specific share of electricity generated by RES in the form of TGCs. This creates a market for green certificates, where the stipulated percentage of total electricity consumption to be obtained from renewable energy sources is referred to as the percentage requirement. By creating a market where renewable electricity producers are rewarded for their green electricity generation, TGCs encourage competition and innovation in the renewable electricity sector (Menanteau et al. 2003). Strong competition in the TGC market is expected to drive down the prices for renewable generated electricity, in order to manage the costs for electricity consumers (Morthorst 2000).

[1] This mechanism is also referred to as Renewable Energy Certificates or Renewable Portfolio Standards in the U.S., and Renewable Obligation Certificates in the United Kingdom.

In this paper, we investigate whether the impact of a TGC system on both profitability and investment behavior varies based on the vertical integration status of the regulated firms. Vertical integration in TGC systems is very prominent because major renewable electricity producers are also electricity retailers (e.g., Coria and Jaraitė 2023). Thus, such firms assume a dual role not only in the electricity market but also in the TGC market – producing TGCs and selling them in the market (supply side) and having an obligation to surrender a particular amount of TGCs to the regulator (demand side). It has been argued that such duality can lead to the manipulation of TGC prices (see, e.g., Amundsen and Bergman 2012; Von der Fehr and Ropenus 2017). On one hand, vertically integrated firms stand to gain from high electricity and TGC prices in their capacity as electricity generators. On the other hand, their obligation to comply with regulatory mandates as TGC-obligated parties may incentivize them to actively pursue lower TGC prices, aiming to minimize the cost of regulatory compliance and thereby to increase overall profits. Vertical integration might also increase the incentives to invest in renewable energy because, in their role as obligated parties, firms must surrender green certificates. Investing in green electricity capacity provides them with a secure and dependable supply of green certificates, allowing them not only to reduce compliance costs, and thus increase profits, but also to mitigate risks associated with regulatory changes.

Does the dual role of vertically integrated firms, concurrently acting as sellers and buyers of TGCs, shape the impact of a TGC system on their profitability and investment incentives? To answer this question, we develop a theoretical model where we compare profits and investments in green electricity under two alternative market configurations involving three firms: an upstream firm producing green electricity and TGC certificates and two downstream firms retailing electricity to final consumers and purchasing TGCs to meet regulatory obligations. Under the non-integration market configuration, the three firms act independently as price takers in the markets for electricity and TGCs. In contrast, under vertical integration, the upstream firm and one of the retailers are owned by the same firm, which makes production and investment decisions to maximize its overall profits.

Based on this simple theoretical model, we hypothesize that vertically integrated firms should not have larger profits than non-vertically integrated firms if (i) the pricing of internally transferred green certificates is aligned with what the upstream firm could obtain by not utilizing the green certificates within its downstream operations but instead selling them in the TGC market, and (ii) vertically and non-vertically integrated upstream firms produce green electricity using technologies with equivalent production costs. Furthermore, we expect vertically integrated RES-E generators to have larger incentives than non-integrated firms to invest in renewable power because they can appropriate a larger part of the incremental value of their investment via a reduced cost of the TGCs that they must source.

We test our theoretical predictions using data for electricity generating and retailing firms operating in Sweden, where a TGC system has been in place since May 2003. We identify causal impacts by leveraging firms' entry dates into the TGC system, employing Sun and Abraham's (2021) event study design, which is robust to staggered dates of implementation and time-varying treatment effects. Essentially, our event-study estimates are constructed as a weighted sum of cohort-specific dynamic treatment effects, where cohorts are defined by the year of TGC entry. Firms belonging to the last cohorts, that is, firms that entered the TGC system during the period 2010-2018, serve as controls.

Our empirical findings broadly align with our theoretical results, revealing no statistically significant variations in profitability between vertically integrated firms and non-integrated RES firms and non-integrated obligated parties. Furthermore, our findings suggest that vertically integrated firms have focused on investing in cost-effective electric capacity, such as hydro and thermal, while non-vertically integrated RES firms have tended to opt for more expensive renewable technologies, such as wind power. Our finding that vertical integration exerts a limited influence on profits in TGC markets reinforces the idea that TGCs can effectively and fairly incentivize renewable electricity generation. Thus, policymakers can view TGCs as a dependable instrument to motivate a diverse array of market participants to invest in and contribute to the expansion of renewable energy capacity.

Our paper contributes to the literature on the effects of vertical integration in electricity markets, particularly in the context of renewable energy markets driven by regulations mandating the demand for green electricity. Previous studies have shown that vertical integration can mitigate market power in electricity markets by aligning incentives within the supply chain (e.g., Mansur 2007; Bushnell et al. 2008; and Aïd et al. 2011). This is because a vertically integrated firm engages in both selling and buying electricity, selling the purchased electricity to retail customers. Consequently, high wholesale prices for electricity supplied to retail customers do not result in additional profits for the firm, but merely shift resources from the retail side to the generation side. Furthermore, in a perfectly competitive market, vertically integrated firms strive to optimize profits across the entire supply chain, implying that internal input prices for their use should align with market prices because these inputs could be sold externally (Bolton and Whinston 1993). Vertical integration should also result in higher capacity investments since expanding capacity helps mitigate uncertainty in compliance costs (see, e.g., Brown and Sappington 2022 and Kim and Samano 2024). Our contribution to such literature lies in offering empirical evidence concerning the impact of vertical integration in renewable energy markets, specifically those brought about by regulations mandating the demand for green electricity.

Our study also contributes to the literature examining market power dynamics within TGC systems, which are believed to facilitate the seamless integration of renewable electricity into established markets. While this integration is expected to encourage competitive pricing for green certificates, concerns arise about market power, especially if incumbent generators secure favorable locations for green electricity generation, such as those in proximity to existing power grids. This scenario can result in their establishment as dominant producers of green electricity and the exertion of market power, potentially affecting both the TGC and electricity markets (see, e.g., Amundsen and Bergman 2012). Our paper contributes to this literature by shedding light on whether vertically integrated firms have gained a competitive advantage by capitalizing on their integrated supply chains to manipulate green certificate prices and squeeze competitors' margins (see, e.g., Von der Ferh and Ropenus 2017). Such a competitive asymmetry could disrupt TGC markets, resulting in increased market concentration, diminished competition, and higher TGC prices.

Finally, our study contributes to the literature analyzing TGC incentives for renewable energy investment. Previous research has examined their impact on renewable capacity and generation (e.g., Yin and Powers 2010, and Deschenes et al. 2023), as well as their efficacy compared them to feed-in tariffs, which provide renewable energy producers with guaranteed compensation for the electricity they inject into the grid (e.g., see Verbruggen and Lauber 2012; and Fabra and Imelda 2023). Feed-in tariffs are often considered more efficient in encouraging investments in renewable energy because the price certainty they provide reduces financial risks for investors and project developers. In contrast, the fluctuation of TGC prices in response to market dynamics introduces uncertainty for project returns (Menanteau et al. 2003; Tamas et al. 2010; Jaraitė and Kažukauskas 2013; Sun and Nie 2015). Our paper contributes to this literature by presenting evidence concerning the specific types of investments incentivized by the TGC system during the initial years following its implementation.

The paper is organized as follows: Section 2 introduces the theoretical model and our hypotheses. In Section 3, we present the main features of the TGC system in Sweden. In Section 4, we describe the data. In Section 5, we present our empirical strategy, followed by a description of the empirical results and some robustness checks in Section 6. Section 7 concludes and discusses the implications of our results.

2 The Model

In TGC systems, renewable electricity is mostly sold in the electricity market at market-clearing prices, but these sales are complemented by green certificate trading in a separate TGC market (Bergek and Jacobsson 2010). In the electricity market, retailers acquire electricity primarily from the wholesale market and subsequently sell it to final consumers.[2] The electricity demand is a decreasing function of the price paid by consumers p_e. This is to say, $D'(p_e) \leqslant 0$. Retailers also are obligated to purchase green certificates from generators, because the retailers are obliged to hold an amount of green certificates in proportion to the level of electricity that they purchase for sale to final consumers. The imposition of this regulation creates a demand for green certificates αQ, where $\alpha \in [0, 1]$ denotes the percentage requirement or quota and Q is the electricity demand.

We consider a simple vertical structure consisting of an upstream firm U providing two inputs — electricity and green certificates — and two downstream firms D_1 and D_2 retailing electricity and purchasing green certificates to meet their regulatory obligations. These firms operate in competitive markets for both electricity and green certificates. The timing of the game is as follows: in the first stage, the upstream firm chooses its level of green electricity capacity I. In the the second stage – the quantity stage – all three firms choose their quantities, and the markets clear.

Because we are interested in the differences in profits between vertically integrated and non-integrated firms, we investigate the effects of the introduction of the TGC system under two alternative market configurations. Under non-integration, firms are owned by three separate owners, i.e., $(NI) : (\{U\}, \{D_1\}, \{D_2\})$. Under vertical integration, firms are owned by two separate owners, i.e., $(VI) : (\{U, D_1\}, \{D_2\})$. Furthermore, we assume that, under NI, downstream firms source all required green certificates from the market at the prevailing market prices. In contrast, under VI, the owner of the integrated firm can unilaterally decide to transfer some of its generated green certificates to its downstream firm.

2.1 Profits and Investments in Green Electricity Capacity under Non-Integration

Let us assume that the two downstream firms have the same cost of retailing electricity, which we assume to be zero. This assumption is purely for simplicity and does not affect the general nature of

[2]Bilateral trading of electricity and TGCs in practice is also possible, but we do not consider it, because most electricity and TGCs are traded in the market in the case of Sweden.

our results; in particular, it makes the analysis especially transparent, as any difference between the profits of downstream firms under different market configurations arises from the enhanced availability of green certificates rather than differences in the cost of retailing electricity. Thus, the profit function of the non-integrated retailer D_i^{NI} can be written as:

$$\pi_{Di}^{NI} = [p_e - p_w]\, q_i - p_g \alpha q_i, \tag{1}$$

where p_e corresponds to the retail electricity price, p_w corresponds to the wholesale electricity price, p_g corresponds to the price of green certificates, q_i corresponds to the quantity of electricity sold by retailer i, and αq_i corresponds to the required number of certificates (given the percentage requirement α). Differentiating equation (1) with respect to the quantity of electricity retailed q_i yields the first-order condition:

$$p_e = p_w + \alpha p_g. \tag{2}$$

In other words, the downstream firms set a competitive retail electricity price that reflects the costs associated with their inputs, which include wholesale electricity and green certificates.

For the upstream firm, the number of green certificates awarded depends on the generation of renewable electricity (hereinafter, green electricity). Let q_c and q_g denote the electricity generated from conventional (c) and renewable energy sources (g), respectively. The profits of the upstream firm are obtained from the sale of conventional and green electricity. It incurs generation costs $c_c(q_c)$ and $c_g(q_g)$ and costs of investment in green electricity capacity equal to $C(I)$.[3] Thus, the profit function of the upstream firm can be written as:

$$\pi_U^{NI} = [p_w q_c + [p_w + p_g]\, q_g - c_c(q_c) - c_g(q_g)] - C(I), \tag{3}$$

The first-order conditions determining the optimal production of conventional and green electricity are:

$$p_w = c_c'(q_c) \tag{4}$$

$$p_w + p_g = c_g'(q_g) \tag{5}$$

[3]Since we are only interested in the investments in green electricity capacity, we assume that there are no further investments in conventional electricity capacity and that the existing capacity for producing conventional electricity is not binding.

implying that the price of green certificates corresponds to:

$$p_g = c_g'(q_g) - c_c'(q_c). \tag{6}$$

This is to say, the price of the green certificates corresponds to the difference between the marginal cost of producing electricity with renewable energy sources and the marginal cost of producing conventional electricity. Replacing equations (4) and (6) into equation (2), we find that the retail price of electricity corresponds to $p_e = [1-\alpha]\, c_c'(q_c) + \alpha c_g'(q_g)$.

Note that – given our assumption about the competitive retail market – the profits of the individual retailers are zero, i.e., $\pi_{D1}^{NI} = \pi_{D2}^{NI} = 0$. In contrast, the upstream firm receives profits given by

$$\pi_U^{NI} = \left[\left[c_c'(q_c)q_c - c_c(q_c)\right] + \left[c_g'(q_g)q_g - c_g(q_g)\right]\right] - C(I), \tag{7}$$

Let us assume a constant unit cost of producing conventional electricity $c_c(q_c) = cq_c$.[4] Under such assumption, equation (7) becomes:

$$\pi_U^{NI} = \left[c_g'(q_g)q_g - c_g(q_g)\right] - C(I). \tag{8}$$

Thus, the non-integrated upstream firm will receive profits as long as the price of green certificates exceeds the costs of producing renewable electricity. Because the price of green certificates should correspond to the cost of the marginal unit of renewable electricity produced in the market, the profits will correspond to the difference between the cost of the marginal unit and the units produced with lower costs.

Finally, let us assume that investing in green electricity generation capacity increases the production of green electricity and the number of green certificates granted to the upstream firm. Differentiating π_U^{NI} in equation (3) with respect to the choice of green electricity generation capacity I, we find that:

$$\left[[p_w + p_g] - c_g'(q_g)\right] \frac{\partial q_g}{\partial I} + \frac{\partial p_g}{\partial q_g}\frac{\partial q_g}{\partial I} q_g = C'(I). \tag{9}$$

[4] This parameterization is borrowed from von der Fehr and Ropenus (2017), who investigate how tradable green certificates allow generators with market power to squeeze the margins of their competitors. In their study, large generators undersupply conventional electricity and oversupply green electricity to limit the market left for competing producers of renewables. In this way, a large generator can shift output and profits toward itself.

Equation (9) outlines the behavior of a non-vertically integrated upstream firm regarding its investments in green electricity capacity. The decision of how much to invest relies on the comparison of marginal net benefits and marginal investment costs.

Breaking down the components of (9), the first term is positive and quantifies the value of green electricity and certificates (net of marginal production costs) multiplied by the incremental green electricity production resulting from the investment in generation capacity. Conversely, the second term captures the potential adverse impact of the investment on the price of green certificates. This term is negative and highlights that, for upstream firms, the motivation to invest in increased green electricity capacity may diminish due to the anticipated negative effect of their investments on TGC prices. The extent of this impact is contingent on both the scale of investment and the prevailing market share of the upstream firm, with larger investments and a substantial market share likely to exacerbate the effects; conversely, the effect might be negligible if the upstream firm lacks a dominant position or if the investment scale is small.

2.2 Effects of Vertical Integration on the Profits of Firms and Incentives to Invest in Green Electricity Capacity

The non-integrated retailer must source all green certificates from the TGC market. Thus, the profit function of D_2 under vertical integration is equal to π_{D2}^{NI} in equation (1), implying that the FOC in equation (2) still hold. Furthermore, since D_2 is a price taker in both the electricity and the TGC market, its profits are still equal to zero.

In contrast, the vertically integrated firm $\{U, D_1\}$ will immediately use αq_1 green certificates in D_1, and will trade any excess of electricity and green certificates in the wholesale and TGC markets at prices p_w and p_g, respectively. Thus, firm $\{U, D_1\}$ maximizes:

$$\pi_{U,D_1}^{I} = [p_e q_1 + p_w [q_c + q_g - q_1] + p_g [q_g - \alpha q_1] - c_c(q_c) - c_g(q_g)] - C(I), \tag{10}$$

where the first term on the right-hand side of the equation (10) corresponds to the sale of electricity in the retail market, the second accounts for the sale of any excess conventional and green electricity in the wholesale market, the third term accounts for the sale of any excess green certificates in the TGC market, and the last three terms correspond to the production costs of both conventional and green electricity, along with the investment costs of green electricity generation capacity.

Differentiating equation (10) with respect to the quantity of electricity retailed q_1 yields the first-order condition:

$$p_e = p_w + \alpha p_g, \tag{11}$$

Furthermore, the first-order conditions that dictate the optimal production of conventional and green electricity are:

$$c_c'(q_c) = p_w, \tag{12}$$

$$c_g'(q_g) = p_g. \tag{13}$$

Substituting equations (11), (12), and (13) into equation (10), we can express the profits of the vertically integrated firm as follows:

$$\pi^I_{U,D_1} = \left[c_g'(q_g)q_g - c_g(q_g)\right] - C(I) \tag{14}$$

Direct comparison of equations (8) and (14) allows us to hypothesize that a vertically integrated RES producer should not have larger profits than a non-vertically integrated RES-producer if (i) the pricing of internally transferred green certificates is aligned with what the upstream firm could obtain by not utilizing the green certificates within its downstream operations but instead selling them in the TGC market, and (ii) vertically and non-vertically integrated RES producers use technologies with equivalent production costs. Under such conditions, it holds that $\pi^I_{U,D_1} = \pi^{NI}_U$.

Furthermore, our analysis allows us to hypothesize that, if conditions (i) and (ii) hold, a vertically integrated retailer should not have larger profits than a non-vertically integrated retailer; this is because vertical integration is profitable for the retailers when the profit of the integrated firm is higher than the sum of profits achieved by the non-integrated retailer and the electricity producer, implying that $\pi^{NI}_{D_1} < [\pi^I_{U,D_1}$ - $\pi^{NI}_U]$. However, as previously indicated, given our assumption about the competitive retail market, the profits of the individual retailers are zero, i.e., $\pi^{NI}_{D1} = 0$, and so is the difference $[\pi^I_{U,D_1}$ - $\pi^{NI}_U]$.

To analyze the effects of vertical integration on investments in green electricity capacity, let us differentiate π^I_{U,D_1} in equation (10) with respect to the choice of green electricity generation capacity I, which leads to:

$$\left[[p_w + p_g] - c_g'(q_g)\right] \frac{\partial q_g}{\partial I} + \frac{\partial p_g}{\partial q_g} \frac{\partial q_g}{\partial I} \left[q_g - \alpha q_1\right] = C'(I). \tag{15}$$

Equation (15) is very much like Equation (9), with the difference that there is less of a reduction in the incentive to invest, due to the downward pressure of the investment on the price of certificates. Indeed, with regard to the case of non-integration, a vertically integrated firm has larger incentives to invest in green capacity because it can appropriate some of the incremental value of its investment via a reduced cost of the green certificates that it must source. Such incentives are represented by the term $-\frac{\partial p_g}{\partial q_g} \frac{\partial q_g}{\partial I} \alpha q_1$, which is positive.

We can thus summarize the hypotheses derived from our theoretical framework to be tested with actual data on the profits and investments of firms participating in the Swedish TGC system. First, vertically integrated firms should not exhibit greater profits than non-vertically integrated firms (either RES producers or electricity retailers) if the pricing of green certificates exchanged internally equates to the prevailing TGC market prices, and if vertical and non-vertical RES producers have equivalent costs of producing green electricity. Second, we expect vertically integrated RES producers to have larger incentives than non-integrated RES producers to invest in green electricity generation capacity because they can appropriate some of the incremental value of their investment via a reduced cost of the green certificates that they must source. In the empirical section, we examine the causal effects of vertical integration by comparing the profits and investments of vertically and non-vertically integrated firms participating in the Swedish TGC system.

3 Electricity and Tradable Green Certificates in Sweden

In Sweden, electricity is traded as a commodity in the multi-national wholesale electricity market Nord Pool. The two major energy sources in the Nord Pool are hydropower (49 percent) located in Norway and Sweden and nuclear power (27 percent) located in Finland and Sweden. The supply side of the Nord Pool is fairly concentrated, where a few major electricity producers have a dominant position in their respective national markets. At the same time, none of them has a share of the Nordic market that exceeds 20 percent. The firm with the largest share of total production is the Swedish state-owned firm Vattenfall (19 percent), followed by the Norwegian state-owned Statkraft (14 percent). The third-largest producer is Fortum (12 percent), of which the Finnish state is the majority owner, followed by the German private energy firm E.ON (7 percent) (Lundin and Tangerås 2020). The Nordic wholesale electricity market is characterized by vertical integration, leading to retailer and producer concentration (Fridolfsson and Tangerås 2009).

Numerous studies have been undertaken to assess market power within Nord Pool, with consistent findings indicating that – despite market concentration – the integration of markets within Nord Pool has led to increased competition (Amundsen and Bergman 2006; Bask et al. 2011). This, in turn, has contributed to a notable decrease in both wholesale and retail profit margins (Amundsen and Bergman 2006).

The Swedish TGC system came into force in May 2003. Producers of electricity from selected sources are awarded a "green certificate" for each MWh of renewable electricity generated. Eligible sources encompass both existing and new electricity generating facilities, such as wind power plants, biomass-based power and combined heat and power plants, geothermal power plants, solar power plants, hydropower plants, and wave power plants.

One distinguishing feature of the Swedish system is that existing power plants were included in the system from the start. One reason for their inclusion was to ensure enough liquidity in the certificate market. Nevertheless, a revision of the system in 2006 limited the support period for these pre-existing plants to either 2012 or 2014, depending on whether the particular plant had previously received government support. New power plants constructed between 2003 and 2021 were guaranteed certificates for a continuous 15-year period. This means that the Swedish TGC system ends in 2035 and is closed for RES-E production facilities that were put into operation after the end of 2021.

Entities obligated to participate in the TGC system are categorized into three groups: (1) electricity suppliers, (2) electricity users (producers/importers), and (3) electricity-intensive industries.[5] Each year, by April 1, these obligated parties must surrender green certificates in accordance with the previous year's percentage requirement, a value determined by the Swedish Parliament. Initially set at 7.4%, this requirement has incrementally risen over time, reaching a value of about 30% in 2018. It will be 27.6 percent in 2035, coinciding with the system's expiration.

[5]According to the regulation, obligated parties are grouped into more categories: (1) professional electricity suppliers that sell electricity to other users, (2) electricity users that consume more than 60 MWh of electricity per year and produce that electricity themselves in a facility with an installed electric capacity higher than 50 KW, (3) electricity users that use imported electricity or buy electricity on the Nordic electricity market, (4) electricity producers that produce electricity in a network that is not subject to a concession and sells more than 60 MWh per year to electricity users on the same network, and (5) electricity-intensive industrial firms that consume at least 190 MWh of electricity for every million SEK of produced value added. However, this categorization was not available to us, as we were provided with the three obligated party categories by the SEA.

Due to liquidity concerns and the potential for a shortage, the initial design of the TGC system included a price ceiling to prevent excessively high prices (and ensure a more predictable market environment). This price ceiling took the form of a penalty for obligated buyers who failed to meet their obligations, which prevented the price of certificates from shooting up (Bergek and Jacobsson 2010). In 2004 and 2005, the fee was increased, but limited to 175 SEK and 240 SEK, respectively.[6] This price cap was, however, removed in the 2006 revision.

The decision to merge the Swedish TGC with the Norwegian system in 2012 was also driven by the recognition that a larger market size could mitigate liquidity concerns and improve the functioning of the market. The expectation was that, by linking the two systems, a larger and more diverse market would be created, allowing for increased trading opportunities and a more stable pricing environment.

Early evaluations of the TGC system suggest that it has reasonably succeeded in advancing renewable energy objectives, even though a significant portion of the initial production was generated by plants already operational in May 2003. This was achieved in part through cost-effective measures, such as increased energy outputs in biomass-based combined heat and power (CHP) plants or conversion from fossil fuels to biomass in existing CHP plants (Bergek and Jacobsson 2010). However, the cost for consumers has been unexpectedly high, due to overcompensation for renewable production in existing plants and overcompensation for more economical technologies, especially as pricier technologies were integrated into the system (Bergek and Jacobsson 2010).

Finally, it is worth mentioning that there is significant cross-ownership in the Swedish TGC market – that is, firms are active on both the demand and supply sides of the TGC market. This cross-ownership is explained by the wave of mergers and acquisitions that took place after the deregulation of the Swedish power market in the late 1990s. Firms participate on both sides of the TGC market directly (i.e., vertical integration where firms operate directly on both sides of the TGC market) or indirectly (where the so-called global ultimate owner owns shares in other firms that directly participate in the TGC market). Coria and Jaraite (2023) have shown that, despite cross-ownership, the market concentration of the entire TGC market is low and has decreased over time.

[6]This fee amounted to 150 percent of the average certificate price in the previous accounting period.

4 Data

4.1 Data sources and data merge

The empirical analysis relies on three data sources: (1) public data about the TGC system provided by the Swedish Energy Agency (SEA), (2) confidential registry data on TGC transactions managed by the SEA, from the Swedish account management system Cesar, and (3) confidential firm-level micro data from Statistics Sweden (SS).

The list of firm-owned RES-E generating facilities that are eligible for receiving TGCs is provided by the SEA. It contains information about each facility's identification number, name, address where the facility is located, owner's (or owners') name, firm registration number (or numbers), installed capacity, type of renewable capacity, and annual received TGCs. According to this data, the number of RES-E facilities has been growing since the start of the TGC system, from 1 589 unique facilities in 2003 to 10 681 unique facilities in 2018. By using firm registration numbers, facility-level data was aggregated to the level of the firm. There were 599 firms and 1 622 firms that received some TGCs for renewable electricity production in 2003 and 2018, respectively.

The data on TGC obligated firms contains information about each obligated firm's name, firm registration number, category according to which an obligated party has an obligation to surrender TGCs to the regulator (see Section 3), and the number of required and surrendered TGCs. There were 447 firms and 628 firms, respectively, that had to surrender some positive amount of TGCs in 2003 and 2018.

Tradable green certificates exist only in electronic format. Firms that are entitled to receive TGCs, firms that are obliged to surrender TGCs, and firms that act as intermediaries in TGCs trading have electronic accounts in Cesar. When a trade is agreed on, TGCs are transferred from a seller's account to a buyer's account. Cesar registers each trade's type of transaction, date of TGCs transfer, volume of TGCs transferred, and price at which TGCs were traded. This data is used to construct some firm-level variables, such as net TGC positions, net cumulative holdings of TGCs, TGC trading volume, and average volume-weighted TGC prices, which we use in our descriptive analysis.

The SS database on firms operating in Sweden was used to retrieve firm outcome variables of interest, such as profits, turnover, fixed assets, investments, and installed electricity capacity. The merging of SEA and SS data was performed by SS personnel. As a result of this merging, we received firm-level anonymized data, which we analyzed remotely on the SS's Microdata Online Access platform, called MONA.

Table 1 describes the main variables used in the analysis, their measurement units, and data sources. The outcome variables in the regression analysis are: operating profit, total profit, operating profit margin (operating profit over turnover), profit margin (total profit over turnover), total wind installed (onshore and offshore) electric capacity, the sum of hydro and thermal installed electric capacity, total fixed assets, investment in machinery and equipment, and net investment in land and buildings. The remaining variables are used to describe the main outcomes of the Swedish TGC system across the status of vertical integration.

To test our hypotheses, in the empirical analysis we consider three firm samples: (1) a sample of vertically-integrated firms, (2) a sample of non-vertical RES firms, and (3) a sample of non-vertical obligated firms. From the vertically integrated and obligated firm samples, we exclude obligated firms that are classified as category 3 firms, as these firms are very different from category 1-2 obliged firms in terms of economic activity (see Section 3). Furthermore, because we use an absorbing treatment design – which means that once the treatment status is switched on, it stays on – we exclude from the analysis firms that appeared in the TGC system for only one year, and we limit the analysis to firms that entered the TGC system no later than 2018. As a result, we removed 10 and 86 unique firms from the RES firms sample and the obligated firms sample, respectively.[7]

4.2 Definition of vertical integration in the Swedish TGC market

Some firms under consideration are vertically integrated in the electricity market, but not in the TGC market.[8] In this section, we describe the procedure that we used to define the status of vertical integration in the Swedish TGC system. It should be noted that both the start and the duration of vertical integration in the Swedish TGC system are heterogeneous across firms. This means that we had to make some simplifying assumptions when constructing a dummy variable ($vertical$) that would allow splitting firms into vertically integrated ($vertical = 1$) and non-vertically integrated ($vertical = 0$) for the period 2000-2018.

We proceeded in two steps. First, we defined an annual vertical integration status if a firm received some TGCs and had an obligation to surrender some TGCs in a particular year. By using this

[7]We do not known why many obligated firms left the TGC system. Given the dynamic nature of the electricity retail market in Sweden, we can guess that some of these firms were on the brink of bankruptcy or in the restructuring phase.

[8]For instance, a vertically integrated firm that generates only conventional electricity is ineligible to receive TGCs, but as a retailer it is required to surrender TGCs.

Table 1: Description of the main variables used in the analysis

Variable name	**Variable description**	**Measurement unit**	**Data source**
Operating profits	Profit from the main firm activity	Millions of SEK	SS
Total profit	Profit from all firm activities	Millions of SEK	SS
Operating profit margin	Operating profit over turnover	Ratio (million SEK/million SEK)	SS and authors' calculations
Profit margin	Total profit over turnover	Ratio (million SEK/million SEK)	SS and authors' calculations
Total fixed assets	Total fixed assets owned by the firm	Millions of SEK	SS
Net investment in land and buildings	Firm net investment in land and buildings	Millions of SEK	SS
Investment in machinery and equipment	Firm investment in machinery and equipment	Millions of SEK	SS
Wind capacity	Electric wind capacity (onshore and offshore) owned by the firm.	KW or GW	SS
Hydro and thermal capacity	Installed electric hydro and thermal capacity owned by the firm	KW or GW	SS
Received TGCs	TGCs received by a particular RES firm every year during the period 2003-2018.	Thousands TGCs or millions of TGCs	SEA
Obligated TGCs	TGCs that had to be surrendered to the regulator on annual basis by a particular obligated firm during the period 2003-2018.	Thousands of TGCs or millions of TGCs	SEA
Net TGC position	Annual net TGC position is calculated as the difference between received TGCs and cancelled TGCs by a particular firm.	Thousands of TGCs	SEA and authors' calculations
Annual cumulative net holdings of TGCs at firm level	Annual cumulative net holdings of TGCs at firm level are calculated by accumulating annual net holdings of TGCs by a particular firm over time. Annual net holdings of TGCs are calculated as the difference between received/bought/imported TGCs and cancelled/sold TGCs/exported by a particular firm: received TGCs + bought TGCs + imported TGCs - cancelled TGCs - sold TGCs - exported TGCs.	Thousands of TGCs	Cesar and authors' calculations
Volume of TGCs transferred	Total volume of TGCs transferred. TGC transfers are categorized into three groups: within-firm TGC transfers, external TGC transfers, and export/import of TGCs.	Thousands of TGCs	Cesar and authors' calculations
Annual average weighted price of TGC at firm level	Volume weighted average price of TGC traded by a particular firm for a particular year	In SEK	Cesar and authors' calculations

Notes: The table provides the list and description of the main variables used in the empirical analysis. SS data is available for the period 2000-2018, except that electric capacity data starts either in 2003 (for wind) or in 2005 (for hydro and thermal). TGC data is available for the period 2003-2018.

definition, we identified the start of vertical integration and the duration of vertical integration in the TGC market for each firm. Table 2 shows that 209 unique firms were vertically integrated in the TGC system at some point during 2003-2018 and that the duration of vertical integration varied from 1 year to 16 years. Most firms became vertically integrated in 2003 – the first year of the TGC system.

Table 2: The starting year and the duration of vertical integration status in the Swedish TGC system

a: Start of vertical integration in the TGC system				**b: Duration of vertical integration status in the TGC system**			
year	# unique firms	%	Cum. %	# years	# unique firms	%	Cum. %
2003	64	30.6	30.6	1	35	16.7	16.7
2004	14	6.7	37.3	2	24	11.5	28.2
2005	6	2.9	40.2	3	21	10.0	38.3
2006	1	0.5	40.7	4	18	8.6	46.9
2007	6	2.9	43.5	5	10	4.8	51.7
2008	4	1.9	45.5	6	6	2.9	54.5
2009	6	2.9	48.3	7	8	3.8	58.4
2010	8	3.8	52.2	8	4	1.9	60.3
2011	4	1.9	54.1	9	14	6.7	67.0
2012	8	3.8	57.9	10	18	8.6	75.6
2013	6	2.9	60.8	11	7	3.3	78.9
2014	8	3.8	64.6	12	11	5.3	84.2
2015	12	5.7	70.3	13	6	2.9	87.1
2016	11	5.3	75.6	14	6	2.9	90.0
2017	21	10.1	85.7	15	7	3.3	93.3
2018	30	14.4	100.0	16	14	6.7	100.0
Total	209			Total	209		

Notes: Panel a of the table provides information about the starting year of the status of vertical integration in the Swedish TGC system. Panel b provides information about the duration of vertical integration in the Swedish TGC system in terms of the number of years. # denotes 'the number of.'

Second, we wanted to ensure that the status of vertical integration in the TGC system is not endogenously determined by the TGC system itself. For instance, we could have a situation in which an obligated firm at some point decided to invest in RES-E capacity to comply with the regulatory mandates. Therefore, to exclude these firms from the vertical firm sample, we assumed that a firm was vertically integrated in the TGC system during the entire period under consideration (2000-2018) if the start of its TGC treatment on the demand side of the TGC system corresponds to the start of its vertical integration in the TGC system, as defined in the first step. In doing so, we have ensured that vertically integrated firms are only those that have been vertically integrated since joining the TGC system.[9]

This exercise resulted in 172 unique vertically integrated firms ($vertical = 1$) in the TGC system during the period 2000-2018, meaning that the remaining 32 TGC obligated firms were moved to the

[9]We cannot completely rule out policy anticipation effects on vertical integration status, meaning that some firms could have decided to become vertically integrated just before the launch of the TGC system. Anticipation effects are to some extent controlled by our identification strategy, which allows estimating the pre-treatment effects for our outcome variables across the treatment and control groups.

non-vertically integrated firm ($vertical = 0$) sample, totaling 539 unique firms on the demand side of the TGC system and 1 849 unique firms on the supply side (see Table 4).

4.3 Descriptive statistics

Table 3 provides the descriptive statistics of the variables used in the empirical analysis. Due to privacy concerns, we were not allowed to report minimum and maximum values, as this would allow identification of a single firm. The data are summarized for the sample running from 2000 until 2018 (with a shorter period for TGC and electric capacity variables, as noted under Table 3), broken down by TGC participation (obligated firms vs. RES firms) and vertical integration status (vertical vs. non-vertical). Not all TGC firms could be identified in the firm data sample provided by the SS, as TGC firms under sole proprietorship (in Swedish, enskild näringsverksamhet) were removed from the SS firm sample because of privacy considerations.

The descriptive statistics exhibit notable differences between vertical and non-vertical firms. Vertical firms, on average, received more TGCs for RES-E generation than non-vertical RES firms (29.6 thTGCs vs. 5.7 thTGCs). On the other hand, non-vertical RES firms, on average, had slightly more wind power capacity than vertical firms (1,794 KW vs. 1,579 KW), while vertical firms had considerably more hydro and thermal capacity than non-vertical RES firms (0.09 GW vs. 0.001 GW). This implies that vertical firms received TGCs mainly for electricity from hydro and thermal power plants, while non-vertical firms received more of their TGCs from wind power plants.

The average TGC obligation for vertical firms was similar in magnitude to the obligation for non-vertical obligated firms (26.0 thTGCs vs. 24.6 thTGCs). However, vertical firms received more TGCs for RES electricity generation than they needed to comply with the TGC system (29.6 thTGCs vs. 26.0 thTGCs). As a result, the average annual net TGC position (received TGCs minus surrendered TGCs) of vertical firms was positive (3.6 thTGCs). On the contrary, non-vertical obligated TGC firms had to source most of the required TGCs on the TGC market and had a negative average TGC position of 23.0 thTGCs.

Vertical firms, on average, received larger operating profits than non-vertical firms (RES or obligated), while average profitability was much larger among non-vertical RES firms than among vertical or non-vertical obligated firms. Another notable difference is that non-vertical obligated firms were on average less profitable than vertical firms.

Table 3: Descriptive statistics of the main variables

Variable name	# obsv.	Mean	Std. dev.
Vertical			
Operating profit	2 549	140.204	784.826
Net profit	2 549	95.839	1 176.694
Operating profit margin	2 497	0.070	0.881
Net profit margin	2 497	0.037	1.979
Turnover	2 549	764.959	3 521.592
Total fixed assets	2 549	2 399.170	15 781.990
Investment in machinery and equipment	2 549	59.939	228.588
Net investment in buildings and land	2 549	44.435	217.288
Wind capacity	2 345	1 578.882	14 070.110
Hydro and thermal capacity	2 345	0.090	0.645
Obligated TGCs	2 345	26.029	187.826
Received TGCs	2 345	29.589	94.218
Net TGCs	2 345	3.561	179.273
Net TGC holdings	2 345	0.018	0.091
RES, Non-vertical			
Operating profit	22 166	11.568	147.706
Net profit	22 166	7.973	132.182
Operating profit margin	21 464	119.975	24 442.590
Net profit margin	21 464	254.297	45 544.650
Turnover	22 166	205.643	3 358.536
Total fixed assets	22 166	303.646	1 973.144
Investment in machinery and equipment	22 166	10.131	144.341
Net investment in buildings and land	22 166	8.912	131.234
Wind capacity	22 634	1 793.626	11 125.370
Hydro and thermal capacity	22 634	0.001	0.021
Obligated TGCs	22 634	1.064	28.075
Received TGCs	22 634	5.653	33.203
Net TGCs	22 634	4.589	43.165
Net TGC holdings	22 634	0.001	0.009
Obligated, Non-vertical			
Operating profit	7 458	102.283	1 001.939
Net profit	7 458	136.200	1 550.723
Operating profit margin	7 239	-1.646	124.076
Net profit margin	7 239	-0.809	178.172
Turnover	7 458	845.577	3 277.125
Total fixed assets	7 458	1 967.569	12 881.910
Investment in machinery and equipment	7 458	32.150	172.592
Net investment in buildings and land	7 458	24.842	183.941
Wind capacity	7 025	27.466	348.456
Hydro and thermal capacity	7 025	0.002	0.020
Obligated TGCs	7 025	24.639	126.965
Received TGCs	7 025	1.629	24.834
Net TGCs	7 025	-23.010	129.189
Net TGC holdings	7 025	0.008	0.067

Notes: TGC and wind capacity data is reported for 2003-2018. Hydro and thermal capacity data is reported for 2005-2018. The remaining variables correspond to 2000-2018. The description and measurement units of each variable are provided in Table 1. # denotes 'the number of.'

5 Identification strategy

The main goal of this paper is to identify the causal effect of the Swedish TGC system on the profitability and investments of the regulated firms and to investigate whether these effects differ across the status of vertical integration. Because a näive comparison of outcomes between vertical firms and non-vertical firms would be plagued by severe systematic differences between these two groups of firms, we utilize staggered participation in the Swedish TGC system, in order to obtain estimates that can be more credibly interpreted as causal. Hence, our empirical approach follows an event study design, and we restrict our sample to ever-treated TGC firms to avoid selecting systematically different control firms. This means that all firms under consideration participated in the Swedish TGC system, but they did so at different times during the period 2003-2018. Table 4 shows the treatment start years for electricity retailers (obligated firms) and renewable electricity generators (RES firms) according to the status of vertical integration.

Table 4: TGC treatment start year, number of unique firms

	# RES firms		**# obliged firms**		**# vertical firms**
	All	Non-vertical	All	Non-vertical	
2003	565	476	269	205	64
2004	65	60	67	58	9
2005	37	36	39	34	5
2006	22	21	12	12	0
2007	45	41	24	19	5
2008	32	29	11	10	1
2009	74	68	19	15	4
2003-2009	840	731	441	353	88
2010	66	64	22	16	6
2011	102	99	14	10	4
2012	60	55	21	13	8
2013	68	65	10	6	4
2014	109	105	38	33	5
2015	131	122	89	82	7
2016	162	158	15	10	5
2017	209	188	19	3	16
2018	274	262	42	13	29
2010-2018	1 181	1 118	270	186	84
Total	2 021	1 849	711	539	172

Notes: The table reports the treatment start year for RES firms, obligated firms, and vertical firms. The start of the treatment for vertical firms as well as for obligated firms is determined on the demand side of the TGC. This explain why the sum of unique non-vertical RES firms and unique vertical firms is not equal to the number of all unique RES firms. # denotes 'the number of.'

Furthermore, given the long period of TGC regulation, we must take into account dynamic treatment effects, as it may take some time for firms to respond to regulation. We also anticipate heterogeneous effects across time because, as we describe in Section 3, the starting years of the TGC market were presumably different from those that followed. We thus worry that the standard two-way fixed effect (TWFE) regression that includes leads and lags of the treatment may suffer from contamination, arising from the fact that becoming subject to regulation at different times may have caused heterogeneous effects on TGC firms' outcomes. Among the different solutions offered by a new strand of econometric literature (Roth et al. 2023), the estimation strategy developed by Sun and Abraham (2021) corrects TWFE regression for contamination issues stemming from cohort-specific dynamic treatment effects. This method uses the proportion of cohorts as weights, because these are more interpretable than the weights implied by the TWFE, and also sum up to unity. The resulting estimates are robust to treatment effect heterogeneity. The identifying assumptions of this method are the same as the assumptions of standard difference-in-differences, including (i) parallel trends in baseline outcomes and (ii) no anticipatory behavior prior to treatment – that is, there is no treatment effect in pre-treatment periods.

The main building block of the estimates is the cohort average treatment effect on the treated, (CATT), defined as the cohort-specific average difference in outcomes relative to a chosen control group. The estimation procedure is implemented in three steps. First, we estimate each CATT using a linear TWFE regression that interacts relative period dummies with cohort dummies. Second, we estimate the weights by sample shares of each cohort in the relative periods. Third, we form the interaction-weighted (IW) estimator by taking a weighted average of estimates for CATT from Step 1 with weight estimates obtained in Step 2. We refer the interested reader to Sun and Abraham (2021) for detailed explanation of the IW estimator.

As for the comparison group, one can either use the never-treated units or the last cohort(s) to be treated. To make the treated and the control group as similar as possible, and to avoid the selection of systematically different control firms, we chose the last-treated cohorts as the most similar. As noted by Sun and Abraham (2021), never-treated entities are likely to behave differently from the last-treated entities; for this reason, we chose the last-treated cohorts as the control group. From Table 4, it is evident that most firms entered the Swedish TGC system in 2003. On the other hand, many firms – be it on the demand side or the supply side of the TGC sytem – became part of the TGC system much later. The heterogeneous treatment start ensures that there are enough firms in the control group.

For instance, in the vertical firm sample there are 88 unique vertical firms that appeared in the TGC system during the period 2003-2009, and 84 other unique vertical firms that entered the TGC system during the period 2010-2018. In the non-vertical RES firm sample, 731 unique firms received TGCs during the period 2003-2009, and 1 118 unique firms received TGCs during the period 2010-2018.

To sum up, our event-study IW estimates are constructed as a weighted sum of cohort-specific dynamic treatment effects, where cohorts are defined by the years of TGC entry date and where firms belonging to the last cohorts (TGC firms that entered into the TGC system during the period 2010-2018) serve as controls. We measure the IW estimates for three firm samples – vertical firms, non-vertical RES firms, and non-vertical obliged firms — separately.

6 Results

6.1 Descriptive results

To begin with, we describe the main outcomes of the Swedish TGC system for vertically integrated and non-integrated (obligated and RES) firms. Figure 1 shows the annual net TGC positions and the annual cumulative net TGC holdings across the status of vertical integration. From panel a1 of this figure, it is evident that vertical firms have had no shortage of TGCs since the beginning of the TGC system, except in 2016 and 2018, while non-vertical obligated firms faced a shortage of TGCs and had to acquire necessary certificates to fulfill their TGC quotas (panel a2 in Figure 1).

Despite these developments, panels b1-b2 in Figure 1 show that vertical and non-vertical obligated firms accumulated positive amounts of TGCs since the beginning of the TGC system. This may suggest that participating firms accumulated TGCs in anticipation of the increasing percentage requirement and the long-term horizon of the TGC regulation. The sizable holdings of TGCs also implies that all obligated firms – vertical and non-vertical – were active on the TGC market. This statement is confirmed by Figure 2, which summarizes the composition of TGC trading across the status of vertical integration during the period 2003-2018. It is evident that both vertically integrated and non-vertically integrated obligated firms were active in trading TGCs outside firm boundaries and on both sides of the TGC market. On the other hand, we observe that vertically-integrated firms were net sellers of TGCs during most years (the amount of TGCs sold was higher than the amount of TGCs bought), while non-vertical obligated firms were net buyers of TGCs (the amount of TGCs bought was higher than the amount of TGCs sold) during the entire period under consideration. Non-vertical RES firms,

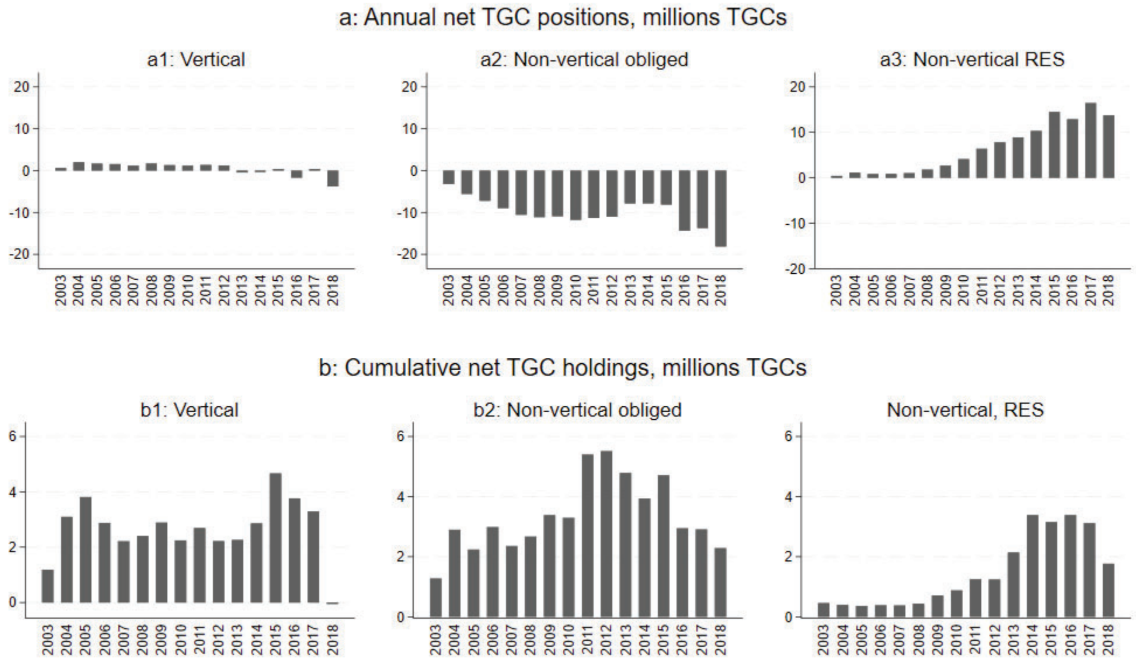

Figure 1: Annual net TGC positions and annual cumulative net TGC holdings

Notes: This figure is compiled by the authors using SEA data. Net TGC position and cumulative net TGC holdings are defined in Table 1.

as expected, were mostly active on the supply side of the TGC market.

Figure 3 reports annual average volume-weighted TGC prices of external TGC transactions across the different firm groups (vertical vs. non-vertical) and across the direction of the transaction (selling vs. buying) during the period 2003-2018. First of all, we observe that – regardless of the status of vertical integration and the direction of the transaction – the dynamics of firm-level TGC prices closely follow the dynamics of the TGC system price. Second, by simple eyeballing, it would be hard to arrive at any strong conclusions about TGC pricing differences between vertical and non-vertical firms. One noticeable difference is that non-vertical obligated firms sold and bought TGCs at slightly higher prices than vertical firms during some years under consideration.

In Figure 4, we report the development of hydro, thermal, and wind electric capacity (in GWs) according to the status of vertical integration during the period 2005-2018. It should be noted that this is the total electric capacity owned by firms under consideration, meaning that not all of it (especially old hydro and thermal) was eligible for receiving TGCs. First, we observe that vertical firms owned

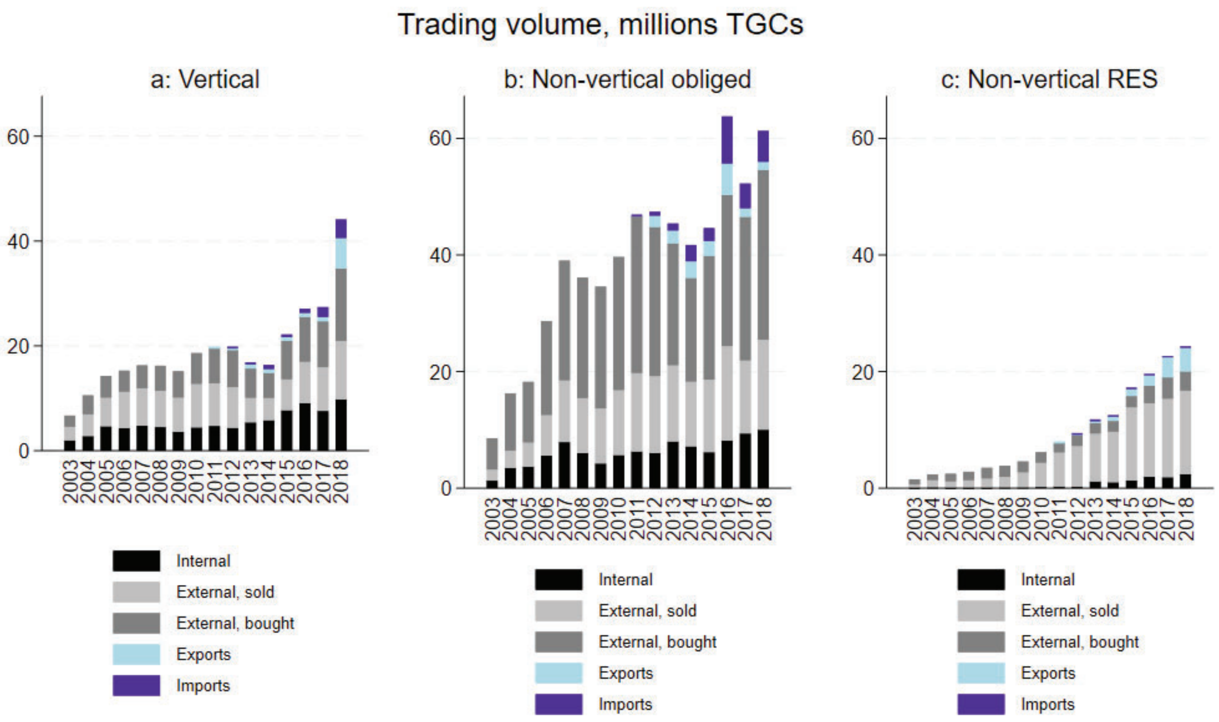

Figure 2: TGC trading volumes in millions of TGCs, 2003-2018

Notes: This figure is compiled by the authors using SEA Cesar data. Exports and imports of TGCs denote flows of TGCs to and from Norway, respectively.

considerably more electric capacity than non-vertical RES firms. Most of the electric capacity owned by these firms was hydro, followed by thermal, while additions to wind power are more noticeable from the year 2013 onward. On the other hand, the electric capacity mix of non-vertical RES firms mainly consisted of hydro and wind power capacity. Another difference between vertical and non-vertical RES firms is that the expansion of wind power capacity started much earlier among non-vertical RES firms than among vertical firms – from the year 2007 onward.

Finally, we compare the development of profits across the status of vertical integration. The data set from SS contains several profit measures, based on financial accounting, including operating profit (profit from the main production activities) and total profit before tax (which takes into account net income from other activities). We consider both profit measures because, for example, we are uncertain about the treatment of the net income from buying and selling TGCs (intangible assets) in financial statements. Furthermore, we are interested in firms' profit margins. Because data available to us do

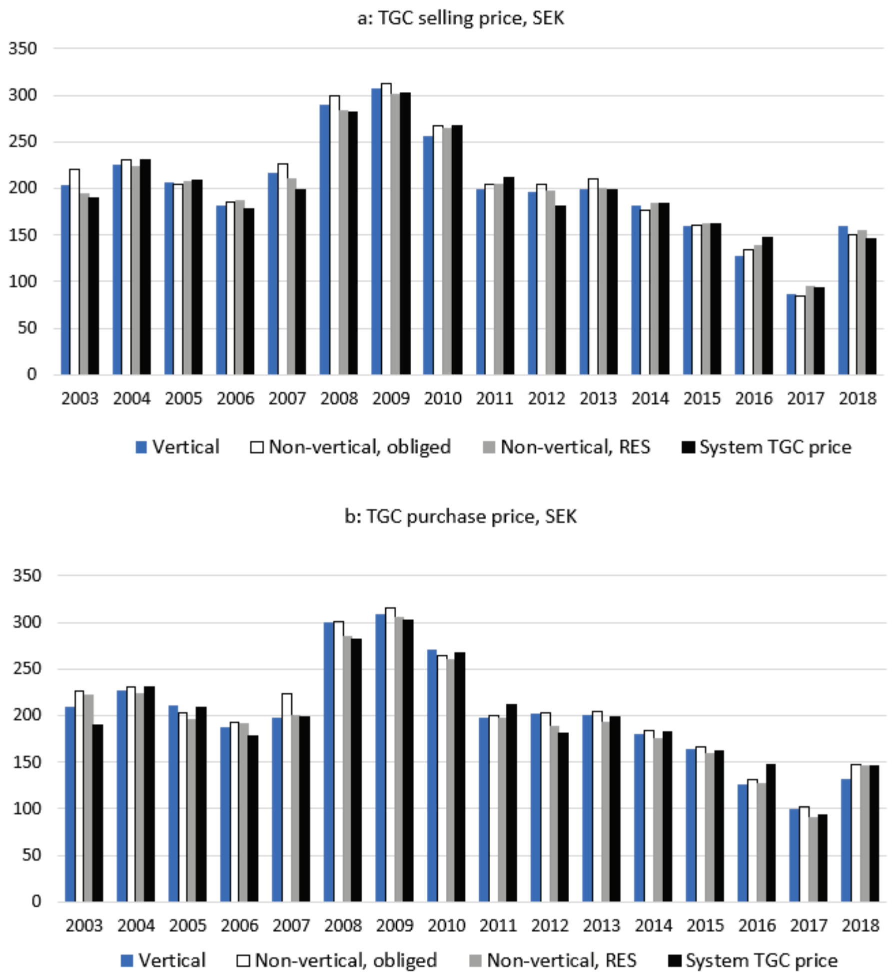

Figure 3: Average annual volume-weighted TGC prices of external TGC transactions in SEK, 2003-2018

Notes: This figure is compiled by the authors using SEA data. The annual TGC system price is the average volume-weighted TGC price recorded by the Cesar registry, which reflects the prices of TGC transactions registered on the Cesar registry.

not allow estimating such margins directly, we calculate proxies by dividing profits by turnover. As a consequence, in our analysis, we consider four profit measures: operating profit, total profit, operating profit margin, and total profit margin.

In Figure 5, we report the annual average operating profit and total profit during 2000-2018. In Figure 6, we report two average annual profit margins – operating profit margin and total profit margin – for the same period. We observe that average profits and average profit margins varied over time and across firm groups. Vertical firms on average had higher operating profits than non-vertical obligated or non-vertical RES firms. Furthermore, average operating profit and total profit followed an increasing

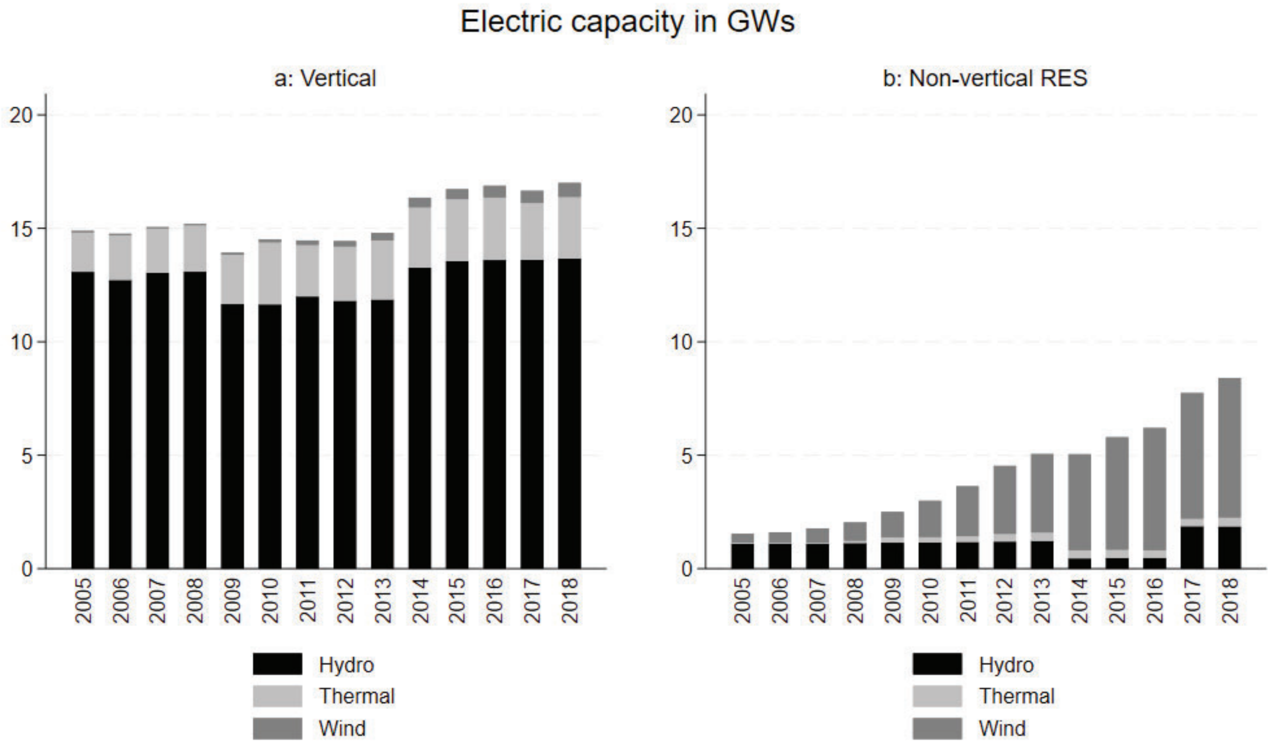

Figure 4: Total installed electric capacity of vertical and non-vertical RES firms in GWs, 2005-2018

Notes: This figure is compiled by the authors using SS data.

trajectory during the period 2004-2008 among all firm groups.

When comparing average annual profitability measures (our proxies for profit margins) across vertical and non-vertical firm groups (see Figure 6), we observe that profitability is much more volatile and of higher magnitude among non-vertical firms (obliged and RES). This confirms our earlier observation that vertically-integrated firms are indeed very different from non-vertically-integrated electricity retailers or electricity producers. Furthermore, it is evident that the average operating profit margin and total profit margin increased among vertically-integrated firms during the first years of the TGC system (2003-2006), while the average profit margins are much higher among non-vertical RES firms during the later years of the TGC system (2010-2015).

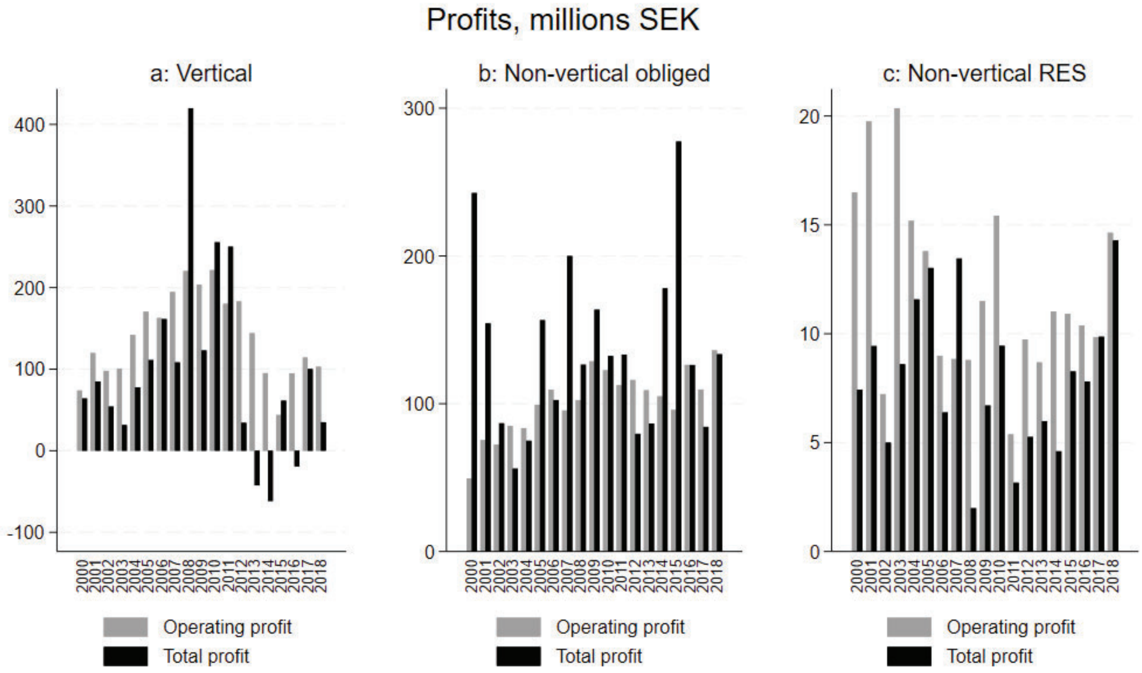

Figure 5: Average annual operating profit and total profit in millions of SEK, 2000-2018

Notes: This figure is compiled by the authors using SS data.

6.2 Event-study estimates

6.2.1 Baseline Results

Figures 7-11 graphically present the estimation results for the IW estimator for our outcome variables of interest using the ever-treated firms' samples of vertical and non-vertical (RES and obligated) firms. We report the point estimates as dots and the 95% confidence intervals as bars. Tables A1-A3 in Appendix A provide the full sets of detailed results, including the standard errors and the number of observations.

Figures 7 and 8 summarize the IW estimates for operating profit, total profit, operating profit margin, and total profit margin. We can validate the absence of pre-trends for all profit measures, at least for the pre-treatment periods that we observe in our data sample ($-3 \leq h =\leq -1$). First, we find that neither vertical firms nor non-vertical RES firms experienced higher operating profits or higher total profits once they joined the TGC system. On the other hand, we observe increases in operating profit for non-vertical obligated firms during 0-2 periods after becoming part of the TGC

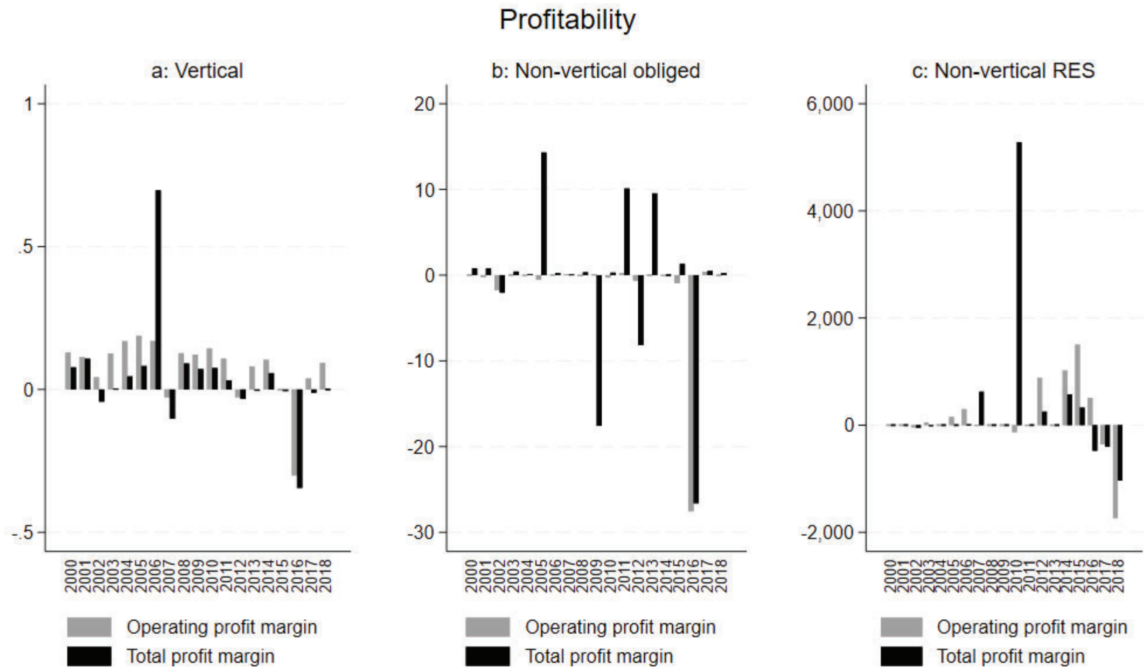

Figure 6: Average annual operating profit and total profit margins, 2000-2018

Notes: This figure is compiled by the authors using SS data.

system ($0 \leq h \leq 2$) (see panel a3 in Figure 7 for the size of the point estimates). These profit measures are absolute and do not take into account the scale of firms' operations. Hence, in Figure 8, we report the estimates for both profit measures scaled by turnover. None of the IW estimates are statistically significant at the 5% level for operating profit margin and profit margin. However, we cannot completely rule out pre-trends for total profit margin for vertical firms in the relevant period $h = -2$ (panel b1 in Figure 8). This means that the results for total profitability of vertical firms should be interpreted with caution.

To summarize, our results for profits and profitability confirm our first hypothesis, stating that vertically integrated firms should not exhibit greater profits than non-vertically integrated firms. This hypothesis holds at least during the first years of the TGC system (2003-2009). This finding might imply that vertical and non-vertical firms faced similar TGC market conditions, despite the fact that vertical firms had a surplus of TGCs, while non-vertical obligated firms have had to source the market to comply with TGC quotas since the very start of the TGC system (see Figure 1). Furthermore, our results run counter to early beliefs (see, e.g., Bergek and Jacobsson 2012) that the Swedish TGC

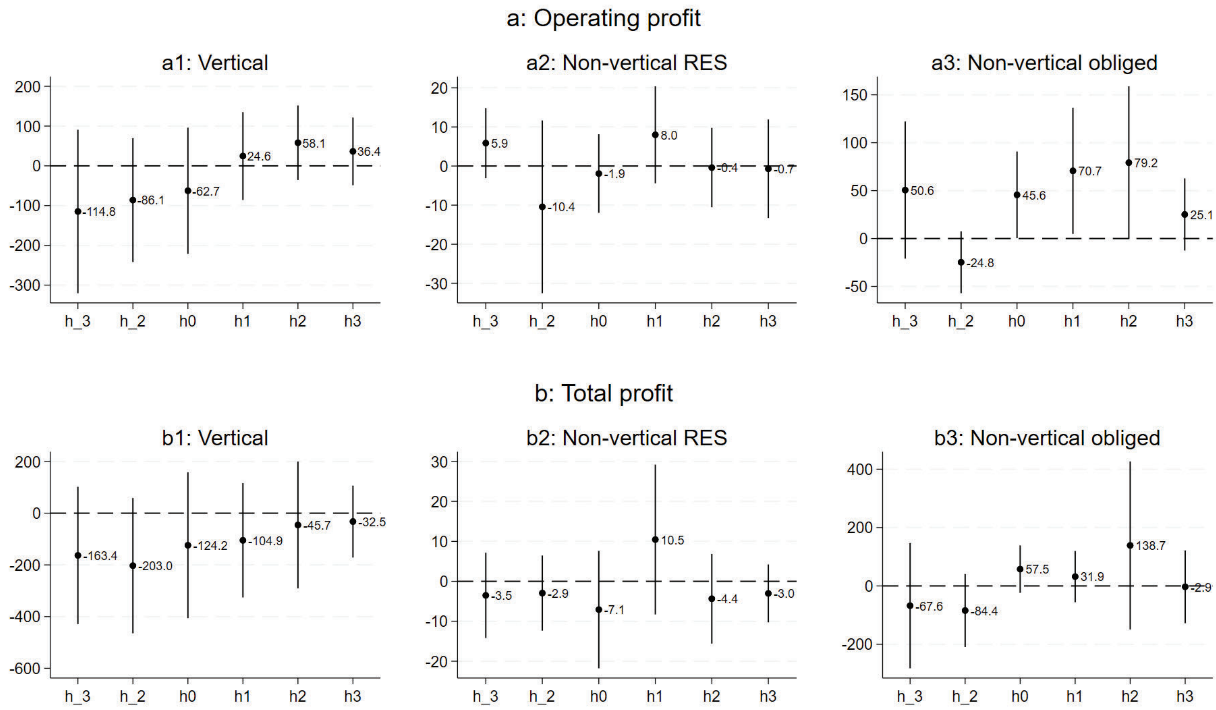

Figure 7: Results for operating profit and total profit

system could generate windfall profits for incumbent firms. Even though the primary focus of our research is not to compare the outcomes of incumbent vs. non-incumbent firms, most of the vertically integrated firms in our sample entered the TGC system immediately in 2003, and many of these firms had large shares of hydro and thermal electric capacity (see Figure 4). This suggests that most of them were indeed incumbent firms that had been active in the electricity market before the start of the TGC system. Nevertheless, a more detailed investigation of these effects would form an interesting topic for future research.

Next, we test our second hypothesis stating that, in the TGC system, vertically integrated firms should have larger incentives than non-integrated upstream firms to invest in green electricity capacity because, as we show in our theoretical framework, a vertically integrated firm can appropriate some of the incremental value of its investment via reduced costs of sourcing green certificates. Because the electric capacity data that was available to us starts either in 2003 (wind) or 2005 (hydro and thermal), and because we expect that some investment decisions were made early on, we also consider additional

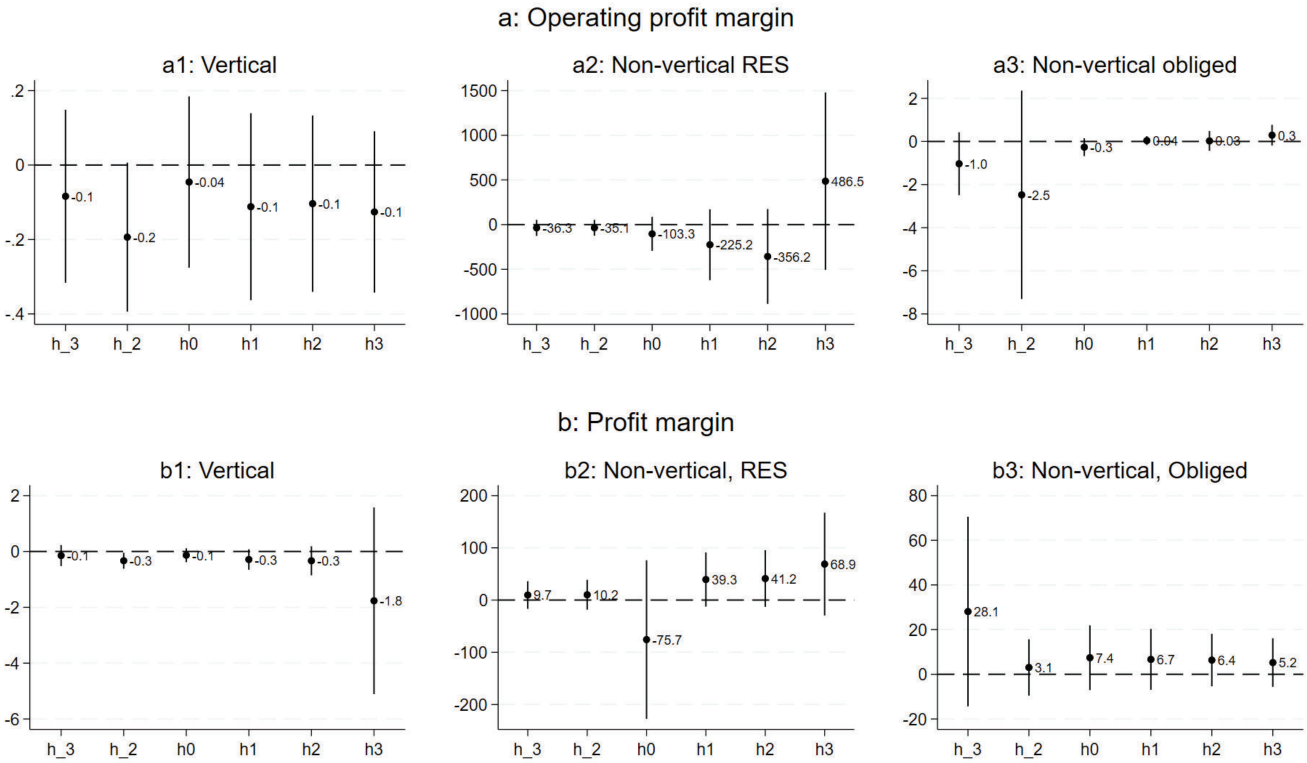

Figure 8: Results for operating profitability and total profitability with ever-treated firms

investment variables from Statistics Sweden, which are available for the entire period under consideration (2000-2018). These include total fixed assets (log), investment in equipment and machinery (log), and net investment in buildings and land. Consideration of firms' capital and investment outcomes is also useful to better understand the long-term effects of the TGC system that we do not consider in our analysis. For instance, we might expect that some investment decisions took place early on but will be realized in electric capacity changes much later on, because it takes a long time to develop new renewable electric capacity (Ambec and Crampes 2019).

Figure 9 presents the estimation results for the IW estimator for total wind electric capacity and total hydro and thermal electric capacity using vertical and non-vertical RES and obligated firm samples. One might think that the results for wind power capacity represent the TGC-induced development of "new" renewable capacity, while the results for the combination of hydro and thermal capacity show

TGC effects on the "old" renewable capacity that was in place before the start of the TGC system.[10] First, we find that vertical firms substantially increased the amount of hydro and thermal electric capacity (by 140%) in year 3 after becoming part of the TGC system ($h = 2$), compared to the corresponding outcomes of the control group, which consists of late-treated vertical firms (panel a1 in Figure 9). On the other hand, vertical firms did not expand wind power capacity after joining the TGC system, at least for the period under consideration (panel b1 in Figure 9).

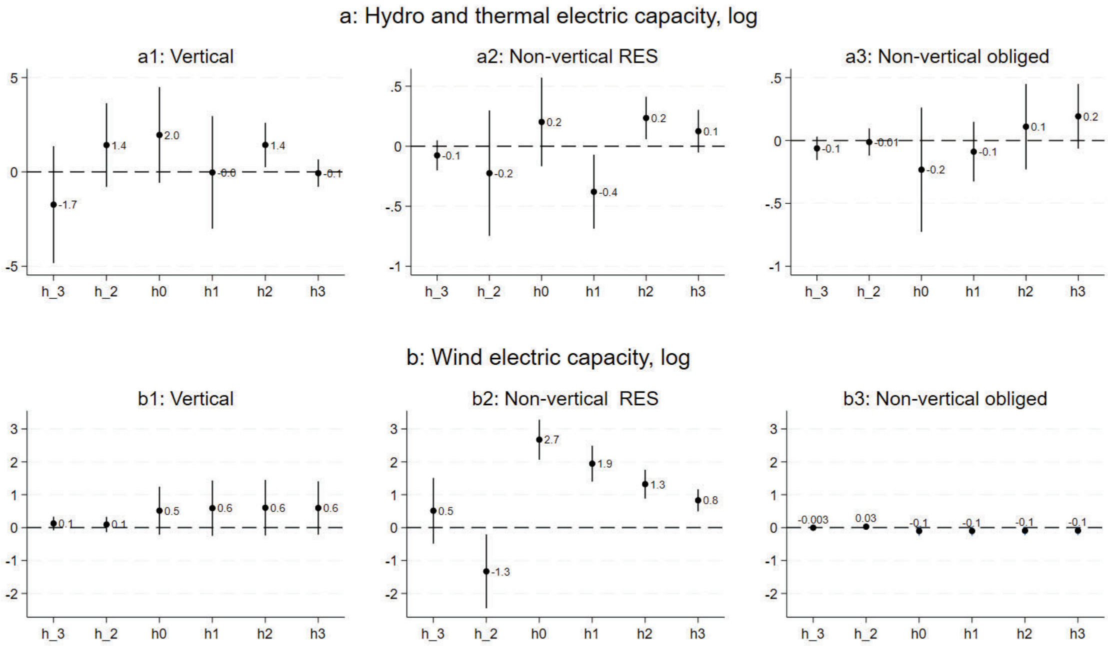

Figure 9: Results for electric capacity with ever-treated firms

Regarding non-vertical RES firms, we observe that these firms expanded not only wind electric capacity, but also hydro and thermal capacity after joining the TGC system (panels a2 and b2 in Figure 9). However, the change is more pronounced and persistent for total wind capacity, as we find that non-vertical RES firms kept increasing wind power capacity during the entire TGC period under consideration ($0 \leq h \leq 3$).

Overall, the results for electric capacity are to some extent confirmed by Figure 4, which presents

[10]We cannot confirm this statement due to data unavailability, but we observe that firms with large hydro and thermal electric capacity existed in the data sample well before 2003. Firms also may have brought new hydro or thermal capacity into operation.

the dynamics of electric capacity across the status of vertical integration. It shows that non-vertical firms were much quicker to expand wind power capacity, while vertical firms adjusted (upward and downward) more hydro and thermal electric capacity. To summarize, our results for electric capacity lend some support for our second hypothesis stating that vertical firms have incentives to invest in green electricity generation capacity. On the other hand, we cannot rule out these incentives for non-vertical RES firms. In other words, based on our results, we cannot conclude that vertically integrated firms had larger incentives than non-integrated power generating firms to invest in green electricity generating capacity, at least during the first years of the TGC system. Last but not least, our results for electric hydro and thermal capacity should be interpreted with caution, as we observe this capacity only from 2005 onward, and as there are few firms that have such capacity in Sweden.

Therefore, to have a better picture about capital changes across vertical and non-vertical firm groups induced by the TGC system, in Figures 10-11, we report the estimation results for total fixed assets, investment in equipment and machinery, and net investment in buildings and land. First, we observe that none of the estimates are statistically significant at the 5% level for total fixed assets, investment in machinery and equipment, or investment in land and buildings for the sample of vertical firms. However, the IW point estimates are positive and significant at the 10% level for investment in machinery and equipment in the relevant periods $h = 0$ and $h = 3$ (see Table A3 in Appendix A). In other words, early-treated vertical firms invested more in machinery and equipment than late-treated vertical firms. Furthermore, we find that non-vertical RES firms increased total fixed assets during 0-3 periods after becoming part of the TGC system ($0 \leq h \leq 3$). The size of these estimates varies from about 10% to about 30% (see panel a2 in Figure 10). Furthermore, these firms also significantly increased investment in machinery and equipment (by about 110%) immediately after joining the TGC system ($h = 0$). For the same firms, we observe a small one-off decrease in net investment in land and buildings (by about MSEK 13) during the relevant period $h = 1$.

To summarize, as in the case of electric capacity, we cannot conclude that vertical firms had more incentives than non-vertical RES firms to invest in capital, such as machinery or equipment or land and buildings, due to the TGC regulation. On the contrary, we find that non-vertical RES firms experienced a long-lasting increase in total fixed assets, which to some extent could be explained by the expansion of machinery and equipment.

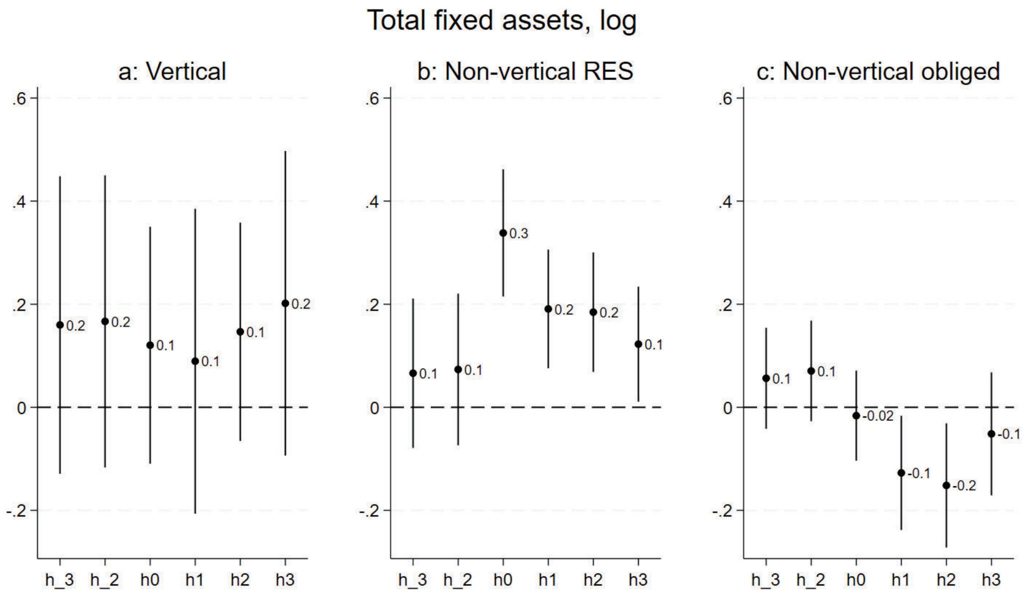

Figure 10: Results for total fixed assets with ever-treated firms

6.2.2 Robustness tests

Online Appendices B and C contain a set of estimation results that probe the robustness of our baseline estimates. In what follows, we discuss briefly the rationale of conducting these robustness tests, and compare the IW estimates from this exercise to the baseline estimates.

Exclusion of Top-10 firms. First, we check whether baseline results are contaminated by outcomes of big firms in terms of TGCs. One might worry that the Swedish TGC system has been dominated by large incumbent electricity producers and big electricity retailers (see, e.g., Coria and Jaraite 2023). The top-10 firms in terms of total green certificates constituted about 50% of the total TGC market on the demand side and about 20% on the supply side during the period 2003-2018. We drop these firms from our sample and rerun the IW estimates, which we summarize in Figures B1-B5 in Appendix B. Based on the results from this exercise, we conclude that the baseline IW estimates are not influenced by the outcomes of top-10 firms.

Alternative definition of vertical integration. Second, one might think that our proposed definition of vertical integration is too lax and, consequently, led to the inclusion of firms that were vertically-integrated in the TGC system for just a short time during the period under consideration. This could

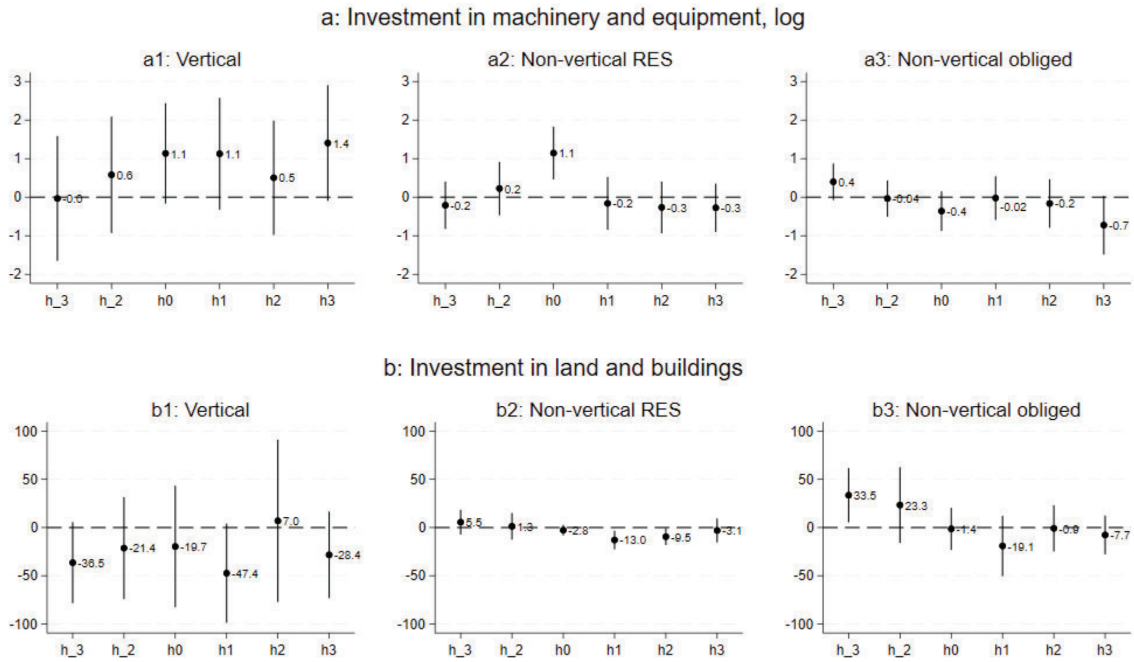

Figure 11: Results for investment in machinery and equipment and net investment in land and buildings with ever-treated firms

potentially explain the one-off effect on electric capacity and the absence of an effect on investment and total fixed assets for the sample of vertically integrated firms. Unfortunately, we could not be too strict in defining vertical firms due to small sample concerns. Hence, in this exercise, we defined vertical firms as before (see Section 4.2) but we added an additional condition, which is that a particular firm is vertically integrated if it was acting on both sides of the TGC system for at least five years during the period 2003-2018. This condition was not applied for firms that entered the TGC market in 2015 and later because these firms are observed for four years at most in our sample. This alternative definition led to 151 unique vertically integrated firms compared to 172 unique vertical firms according to the baseline definition. In other words, as a consequence of the alternative definition, 21 firms were moved from the sample of vertical firms into the sample of non-vertical firms. Figures C1-C5 in Appendix C summarize the IW estimates, from which we conclude that our baseline results are robust to the alternative definition of vertical integration.

Sample trimming. Finally, in the last robustness exercised, we trimmed our sample by excluding the 2% largest and 2% smallest firm-year values of profit margin as we saw that profitability varies a lot across firms and therefore we might worry that several outliers might affect the IW estimates. However, we should point out that we have neither scientific nor statistical justification to identify which observations are data error and which are not. Hence, the results of this exercise should be taken with the grain of salt and not considered as superior over the baseline results. Figures D1-D5 in Appendix D summarize the IW estimates. The main difference between the baseline IW estimates and the IW estimates from the trimmed sample is that we observe pre-trends in profit margins for the trimmed sample of non-vertical RES firms, which potentially reflect the anticipation of the TGC regulation. Overall, we conclude, that our baseline results are robust to the results from the trimmed sample.

7 Conclusions

Historically, vertical integration has been a prominent feature in energy markets, particularly within the domains of electricity production and retailing. While concerns exist about the potential negative impact of vertical integration on market power, contrasting viewpoints suggest that such integration might also serve to alleviate market power concerns. The divergence of opinions underscores the complexity of evaluating the effects of vertical integration in energy markets.

In this paper, we investigated the implications of vertical integration in tradable green certificate systems from theoretical and empirical perspectives. This form of integration provides companies with the opportunity to diversify their revenue streams while ensuring compliance with regulatory mandates. A noteworthy advantage of vertical integration in TGC systems is the ability of the integrated retailer to internally utilize the TGCs it produces. This internal use of TGCs offers the integrated retailer a reliable and guaranteed supply of green certificates, effectively mitigating the risks associated with potential shortages of TGCs or TGC price volatility, and potentially leading to reduced compliance costs and greater profits in comparison to non-vertically integrated retailers.

We developed the theoretical model to investigate whether the effects of a TGC system differ across the status of vertical integration and made use of data from Sweden to test two hypotheses. First, we hypothesized that vertically integrated firms in a TGC system should not exhibit greater profitability than non-vertically integrated firms. This holds true under two conditions: (i) the pricing of internal TGC transactions aligns with what the upstream firm could achieve by not utilizing the green certificates internally but instead selling them in the market; and (ii) production costs are the same between vertical and non-vertical firms. Second, we anticipated that vertically integrated firms would exhibit greater incentives to invest in green electric capacity compared to their non-integrated counterparts. This expectation arises from the ability of vertically integrated firms to capture a larger share of the incremental value of their investments, stemming from reduced green certificate sourcing costs compared to non-integrated firms.

Our empirical analysis and robustness checks supported to a large extent our theoretical considerations, in that we did not observe statistically significant differences in profits (absolute and relative) across the status of vertical integration. Notably, our results also suggest that vertically integrated firms have strategically invested in cost-effective measures, such as hydro and thermal electric capacity. In contrast, non-vertically integrated RES entities seem to have opted for pricier renewable technologies, notably wind power. Thus, vertically integrated firms, historically possessing cost-effective technologies such as hydro and thermal electric capacity, appear to have leveraged these low-hanging fruit opportunities. In contrast, the additions to wind power capacity are predominant many years after the introduction of the TGC system, suggesting a delayed adoption of this technology.

The study's implication that vertical integration does not strongly influence profits in TGC markets reinforces the notion that TGCs can serve as an effective and equitable mechanism for promoting renewable energy. Policymakers may view TGCs as a reliable tool for encouraging a broad range of market participants to invest in and contribute to the growth of renewable energy capacity.

Finally, it is important to acknowledge the limitations of the study. One notable limitation is that our approach permits the determination of the causal effect of the Swedish TGC system only during the initial years of the system's operation. While this timeframe aligns with the period when concerns about market power were most pronounced, it also places constraints on our ability to comprehensively assess the longer-term effects of this TGC system, especially regarding investments that may take time to manifest in the market. The evolving nature of renewable energy markets, technological advancements, and changing regulatory landscapes may lead to shifts in investment strategies and patterns that extend beyond the timeframe covered by our study. Future research and assessments could build upon our findings, considering the changing dynamics and addressing these temporal constraints.

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Appendix A: Detailed Baseline Results

Table A1: Detailed results for profit measures

Relative period	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Operating profit						
	Vertical		Non-vertical RES		Non-vertical obligated	
h_3	-114.8	104.8	5.9	4.571	50.6	36.5
h_2	-86.1	79.5	-10.4	11.269	-24.8	16.4
h0	-62.7	80.9	-1.9	5.128	45.6	23.1
h1	24.6	56.4	8.0	6.326	70.7	33.6
h2	58.1	47.8	-0.4	5.179	79.2	40.7
h3	36.4	43.4	-0.7	6.428	25.1	19.2
# obsv.	1 234		9 451		3 879	
# unique firms	134		1 121		425	
Total profit						
	Vertical		Non-vertical RES		Non-vertical obligated	
h_3	-163.4	135.4	-3.5	5.4	-67.6	109.5
h_2	-203.0	133.4	-2.9	4.8	-84.4	63.8
h0	-124.2	143.9	-7.1	7.5	57.5	41.5
h1	-104.9	112.8	10.5	9.6	31.9	44.8
h2	-45.7	125.0	-4.4	5.7	138.7	146.8
h3	-32.5	70.9	-3.0	3.7	-2.9	63.6
# obsv.	1 234		9 451		3 879	
# unique firms	134		1 121		425	
Operating profit margin						
	Vertical		Non-vertical RES		Non-vertical obligated	
h_3	-0.084	0.119	-36.3	45.7	-1.033	0.744
h_2	-0.194	0.102	-35.1	45.1	-2.476	2.466
h0	-0.046	0.117	-103.3	96.9	-0.264	0.211
h1	-0.112	0.128	-225.2	202.5	0.041	0.106
h2	-0.104	0.121	-356.2	270.7	0.027	0.235
h3	-0.126	0.111	486.5	506.9	0.293	0.245
# obsv.	1 217		9 131		3 780	
# unique firms	131		1 077		418	
Profit margin						
	Vertical		Non-vertical RES		Non-vertical obligated	
h_3	-0.147	0.193	9.7	13.5	28.1	21.7
h_2	-0.331	0.146	10.2	14.6	3.1	6.4
h0	-0.135	0.127	-75.7	77.5	7.4	7.4
h1	-0.288	0.187	39.3	26.5	6.7	6.9
h2	-0.334	0.265	41.2	27.7	6.4	6.0
h3	-1.768	1.706	68.9	50.2	5.2	5.5
# obsv.	1 217				3 780	
# unique firms	131				418	

Table A2: Detailed results for electric capacity

Relative p.	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
	Hydro and thermal electric capacity, log					
	Vertical		Non-vertical RES		Non-vertical obliged	
h_3	-1.736	1.581	-0.076	0.064	-0.062	0.048
h_2	1.423	1.131	-0.225	0.267	-0.012	0.055
h0	1.960	1.293	0.202	0.188	-0.233	0.252
h1	-0.027	1.524	-0.380	0.158	-0.089	0.121
h2	1.429	0.602	0.235	0.090	0.110	0.173
h3	-0.065	0.369	0.125	0.090	0.192	0.131
# obsv.	655		5 895		2 029	
# unique firms	137		1 242		421	
	Wind electric capacity, log					
	Vertical		Non-vertical RES		Non-vertical obliged	
h_3	0.127	0.105	0.513	0.508	-0.003	0.004
h_2	0.094	0.118	-1.330	0.573	0.028	0.022
h0	0.514	0.372	2.673	0.310	-0.102	0.074
h1	0.591	0.429	1.943	0.277	-0.102	0.074
h2	0.604	0.430	1.321	0.224	-0.094	0.068
h3	0.597	0.413	0.829	0.171	-0.093	0.067
# obsv.	925		7 999		2 825	
# unique firms	138		1 244		427	

Table A3: Detailed results for investments and total fixed assets

Relative p.	Coeff.	Std. Err.	Coeff.	Std. Err.	Coeff.	Std. Err.
Total fixed assets, log						
	Vertical		Non-vertical RES		Non-vertical obliged	
h_3	0.160	0.147	0.066	0.074	0.056	0.050
h_2	0.167	0.145	0.073	0.075	0.071	0.050
h0	0.120	0.117	0.338	0.063	-0.016	0.045
h1	0.089	0.151	0.191	0.059	-0.127	0.057
h2	0.146	0.108	0.185	0.059	-0.152	0.061
h3	0.202	0.151	0.123	0.057	-0.052	0.061
# obsv.	1 215		9 289		5 091	
# unique firms	134		1 102		547	
Investment in machinery and equipment, log						
	Vertical		Non-vertical RES		Non-vertical obligated	
h_3	-0.033	0.825	-0.210	0.314	0.400	0.242
h_2	0.580	0.770	0.226	0.354	-0.035	0.240
h0	1.136	0.664	1.144	0.347	-0.361	0.262
h1	1.127	0.739	-0.160	0.350	-0.022	0.288
h2	0.505	0.756	-0.265	0.342	-0.164	0.322
h3	1.405	0.766	-0.274	0.319	-0.725	0.389
# obsv.	1 243		9 451		5 140	
# unique firms	134		1 121		549	
Net investment in land and buildings						
	Vertical		Non-vertical RES		Non-vertical obligated	
h_3	-36.5	21.4	5.5	6.5	33.5	14.3
h_2	-21.4	27.0	1.3	7.1	23.3	20.0
h0	-19.7	32.2	-2.8	2.8	-1.4	11.2
h1	-47.4	26.2	-13.0	4.9	-19.1	15.9
h2	7.0	42.9	-9.5	4.5	-0.9	12.3
h3	-28.4	22.9	-3.1	6.3	-7.7	10.3
# obsv.	1 243		9 451		3 879	
# unique firms	134		1 121		425	

Appendix B: Robustness Test No. 1, Exclusion of Top-10 firms

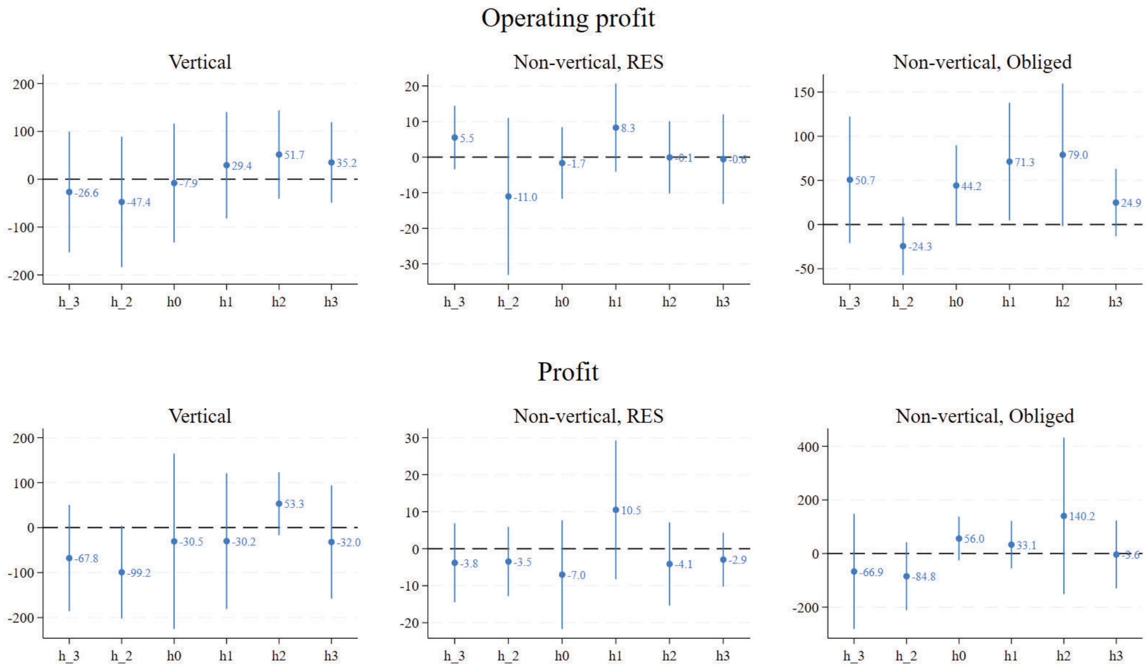

Figure B1: Results for operating profit and total profit

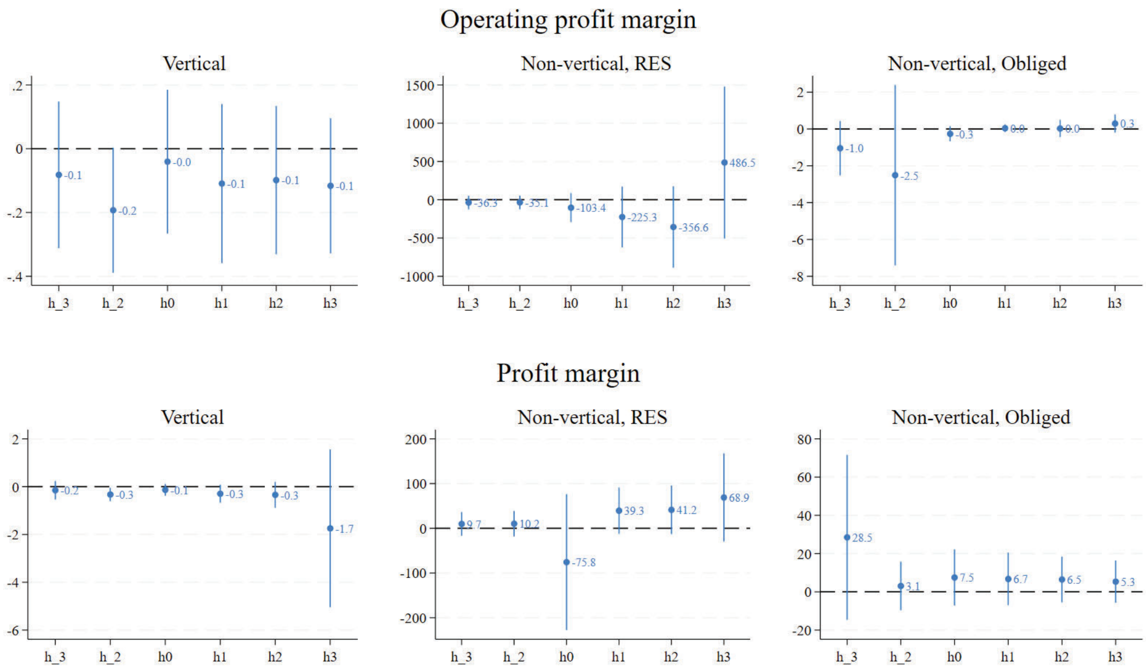

Figure B2: Results for operating profit margin and total profit margin

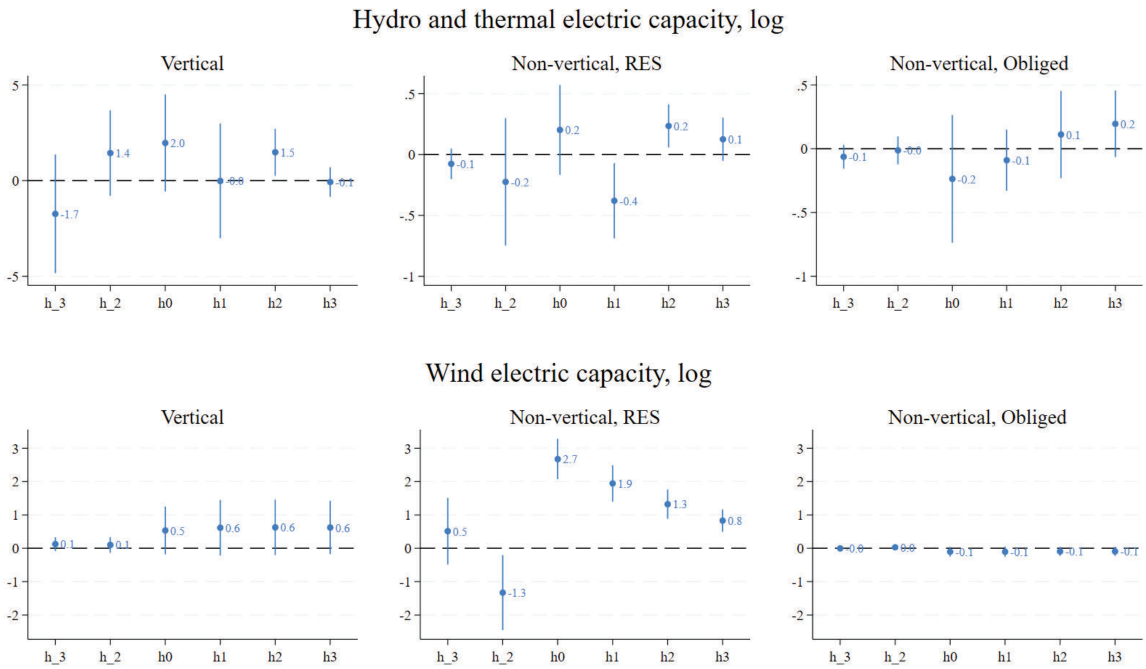

Figure B3: Results for hydro, thermal and wind electric capacity

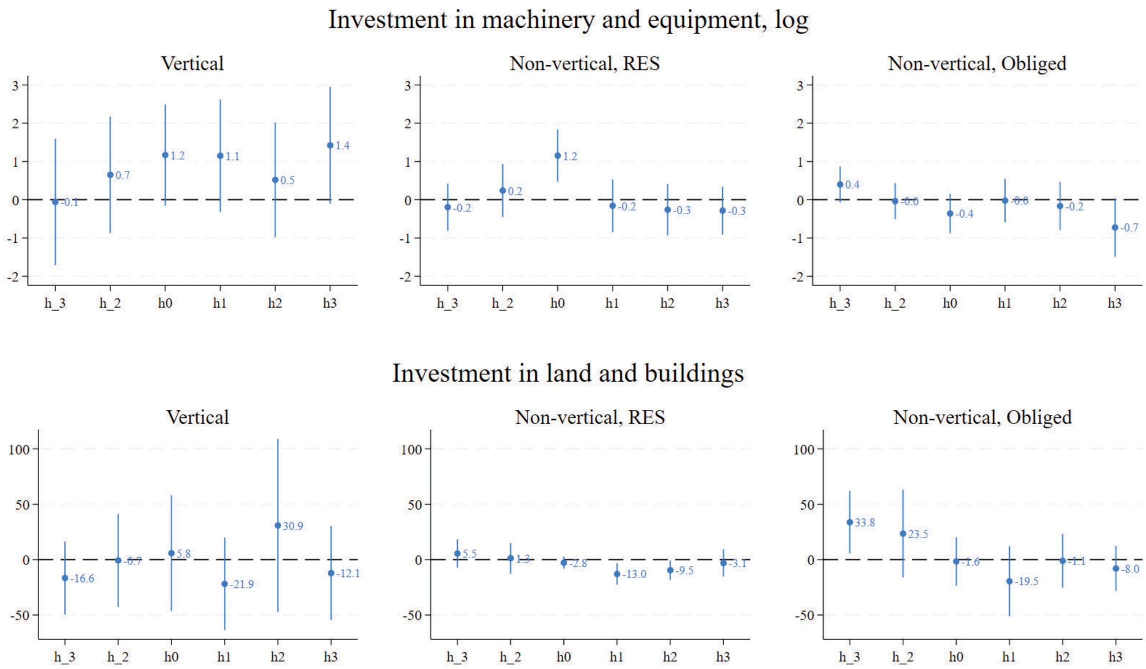

Figure B4: Results for investment

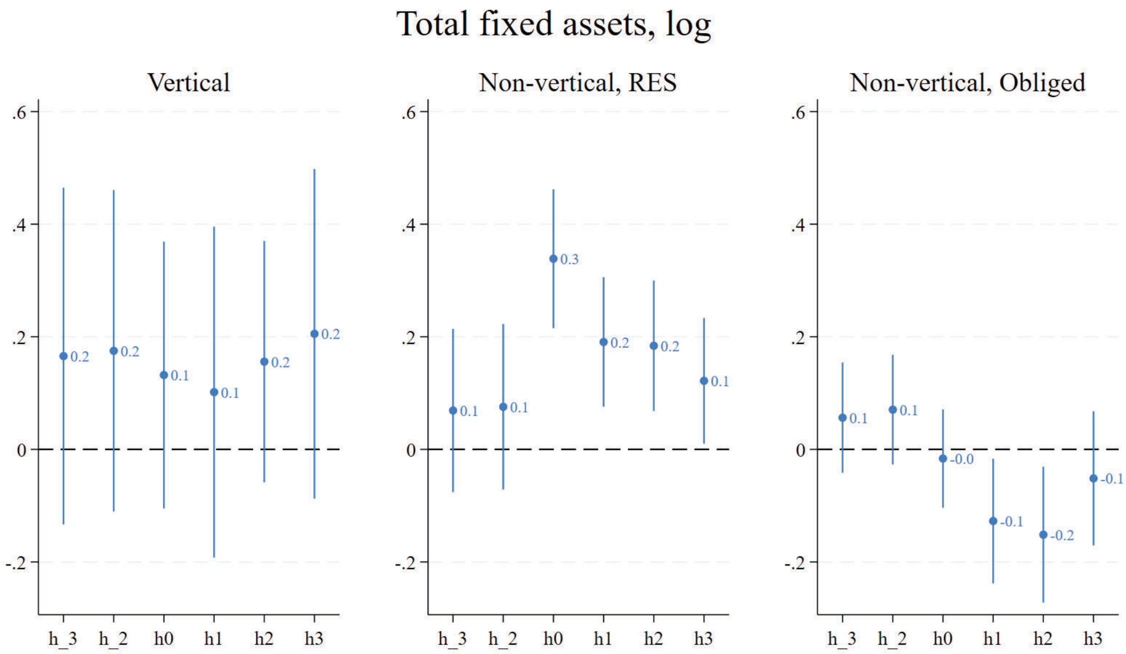

Figure B5: Results for total fixed assets

Appendix C: Robustness Test No. 2, Alternative Definition of Vertical Integration

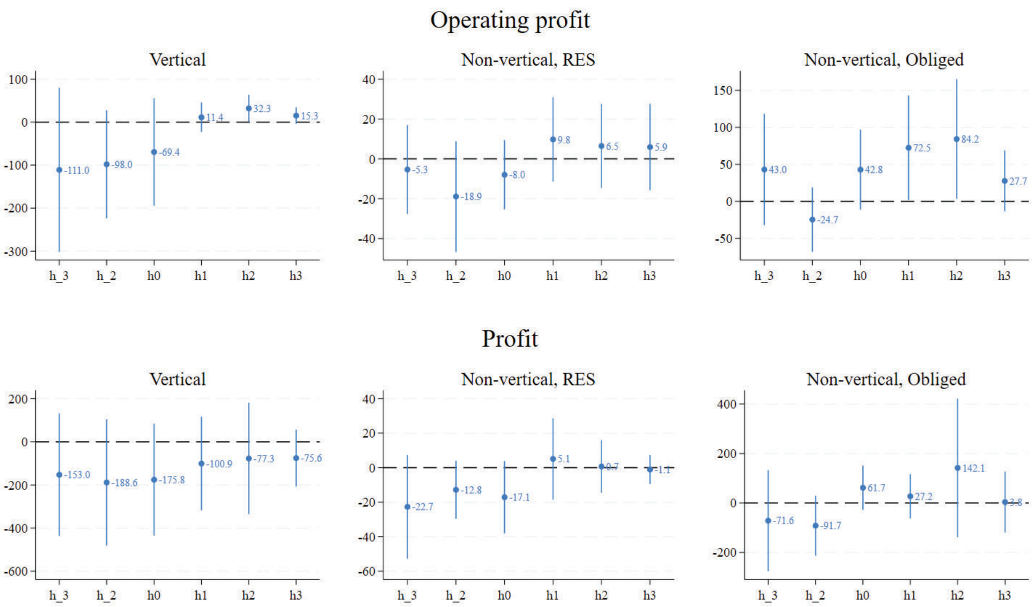

Figure C1: Results for operating profit and total profit with ever-treated firms

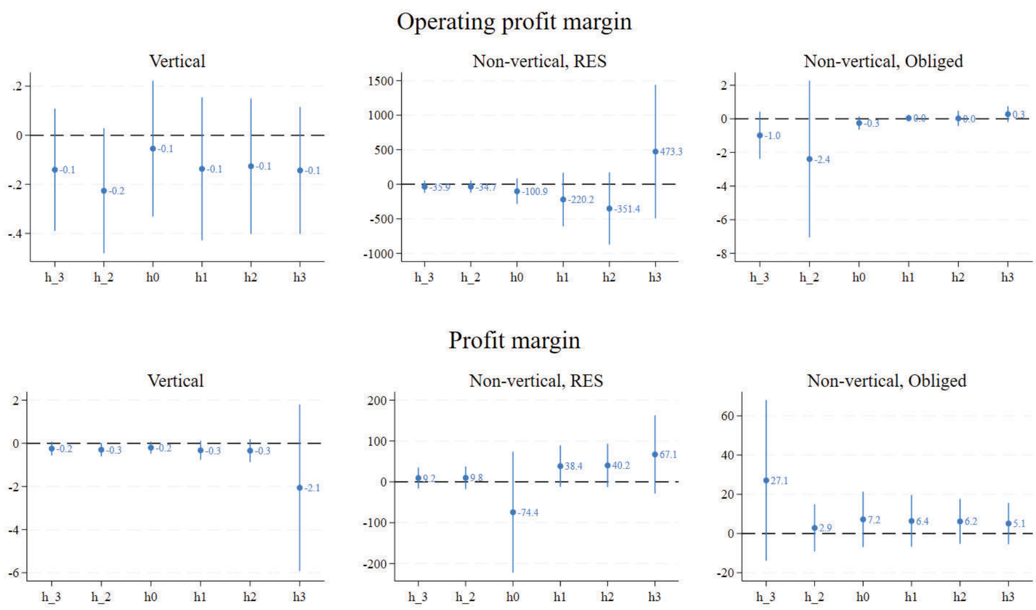

Figure C2: Results for operating profit margin and total profit margin

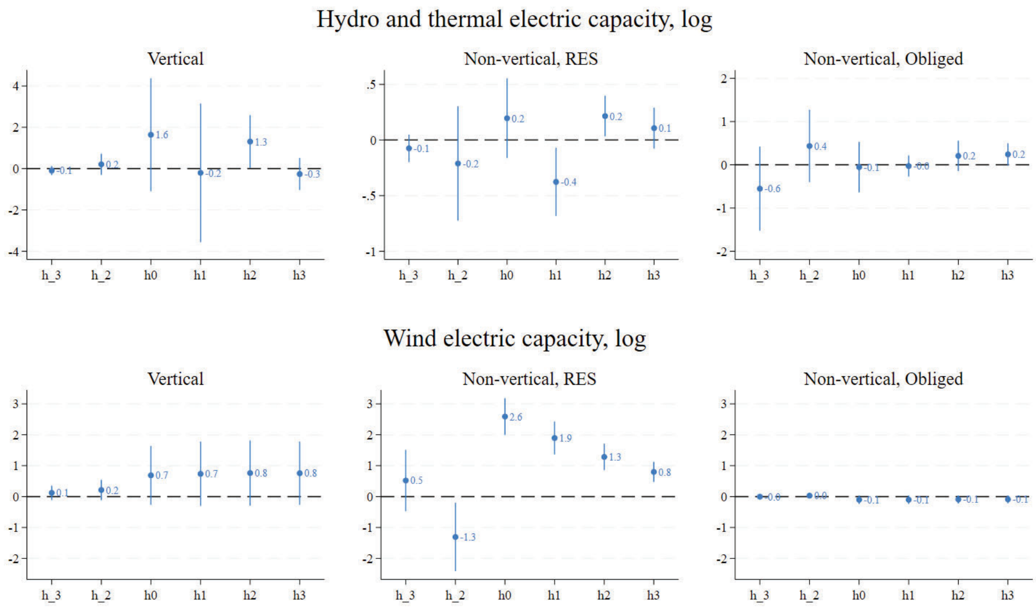

Figure C3: Results for hydro, thermal and wind electric capacity

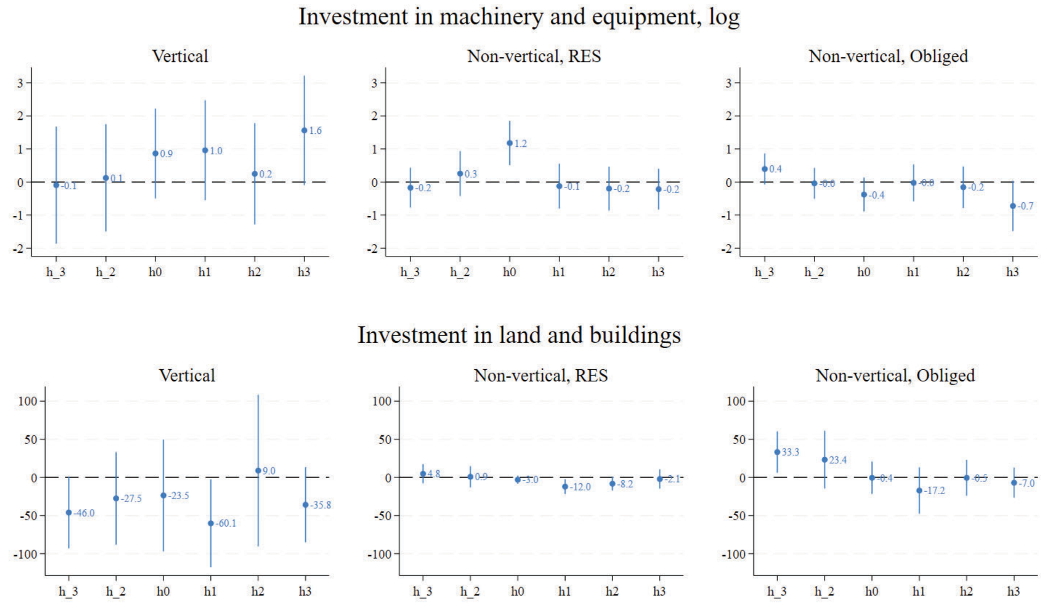

Figure C4: Results for investments

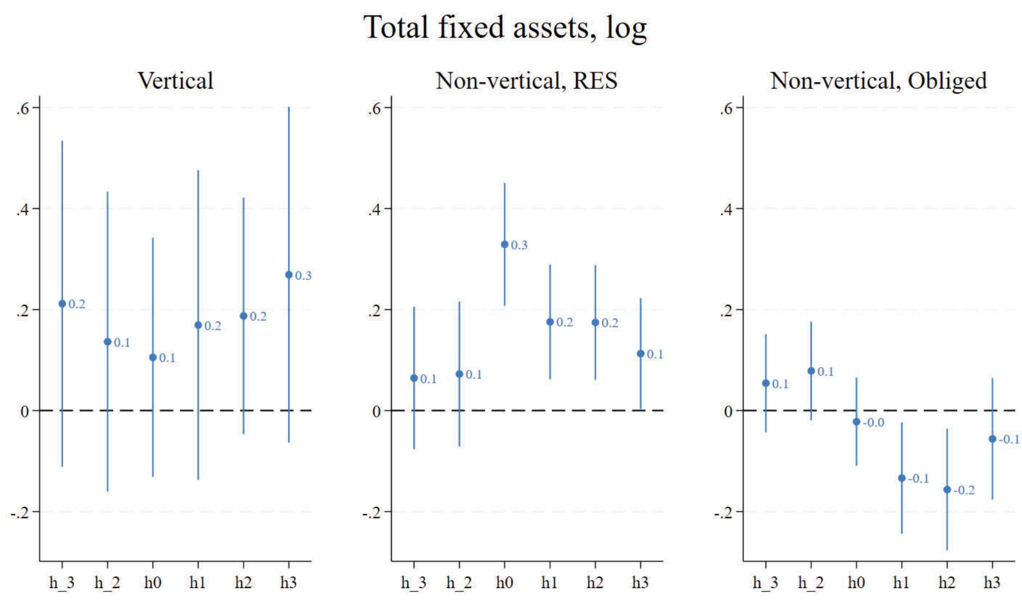

Figure C5: Results for total fixed assets

Appendix D: Robustness Test No. 3, Trimmed Sample

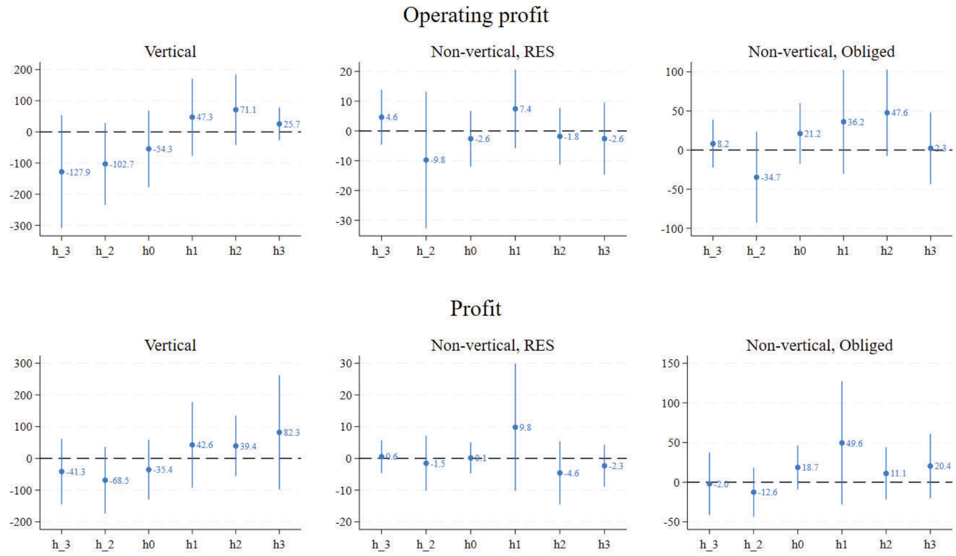

Figure D1: Results for operating profit and total profit with ever-treated firms

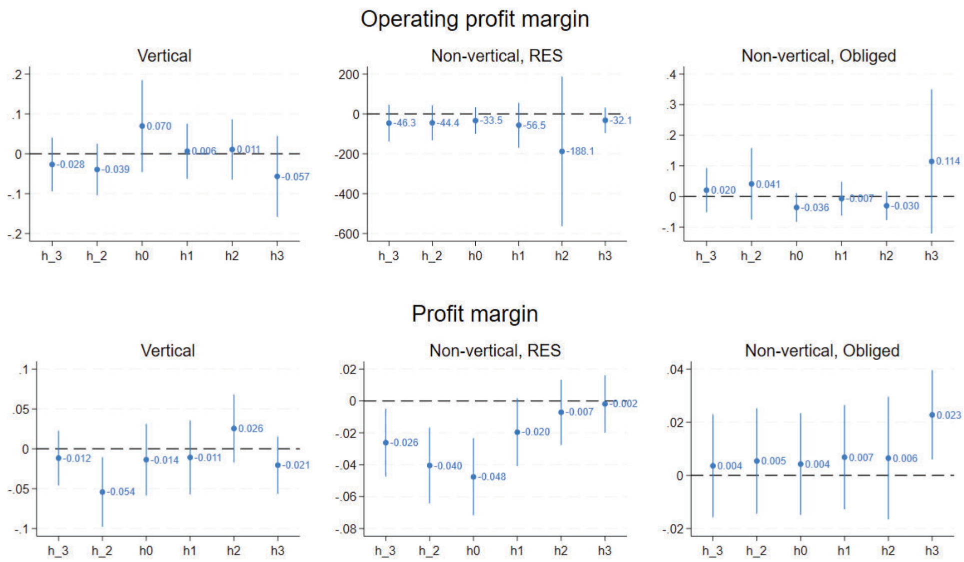

Figure D2: Results for operating profit margin and total profit margin

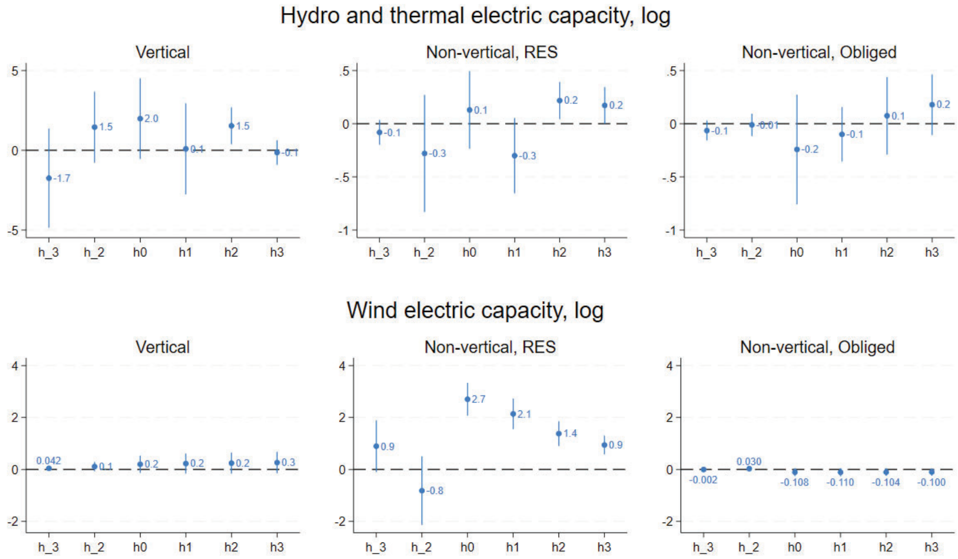

Figure D3: Results for hydro, thermal and wind electric capacity

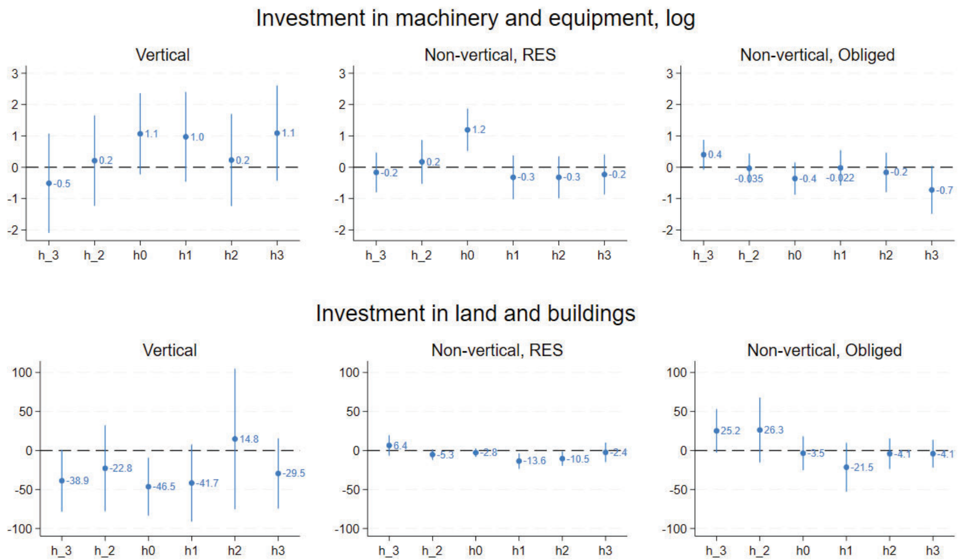

Figure D4: Results for investments

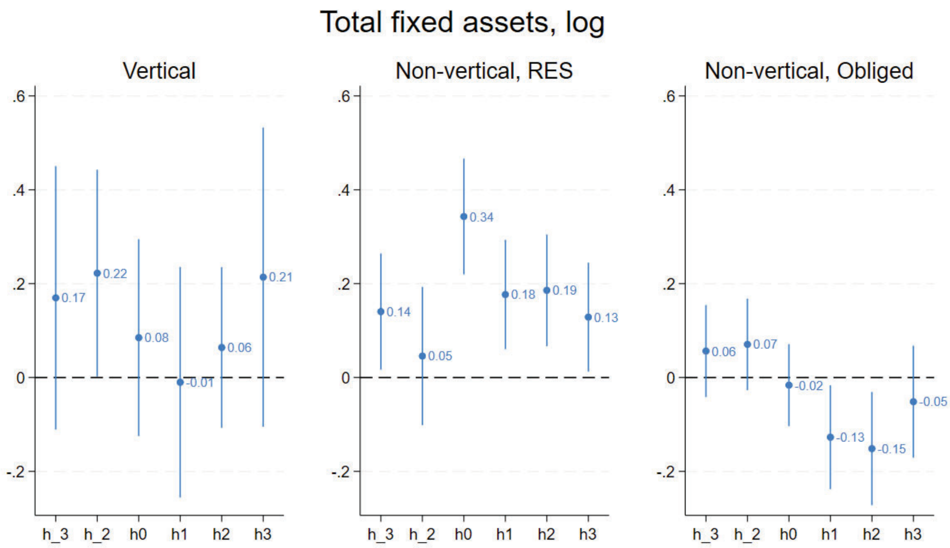

Figure D5: Results for total fixed assets