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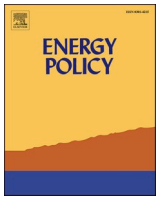

Ownership structure and prices: A case study of the Swedish tradable green certificate market

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ABSTRACT

This paper studies the ownership structure among participants in the Swedish tradable green certificate (TGC) system and its implications for TGC prices. First, we investigate cross-ownership – a situation when a firm is active on both the demand and supply sides of the TGC market – by linking suppliers and obliged parties to their parent firms. Next, we calculate indexes of market concentration that account for cross-ownership. Finally, we use detailed TGC transaction-level data to analyze differences in the prices of the TGCs traded by cross-ownership versus non-cross-ownership firms. Our results show considerable cross-ownership, with many firms active on both TGC supply and demand sides. However, even after accounting for cross-ownership, the market concentration of the entire TGC market is low and has decreased over time. Despite the absence of market concentration, our analysis of TGC prices indicates that cross-ownership firms have the ability to differentiate TGC prices from non-cross-ownership firms. Such behavior is consistent with the behavioral assumption that the ultimate owner's objective is to maximize the total profit of the portfolio of shares, and that, therefore, the pricing behavior would differ from that of a perfectly competitive firm without ownership links to other firms in the industry.

1. Introduction

Sweden has one of the world's most ambitious climate and energy goals. The national climate policy framework has the long-term goal of net zero emissions of greenhouse gases by 2045. This is to be achieved through increased energy efficiency and 100 percent renewable electricity production by 2040. A key policy to increase the production of renewable electricity is the Swedish tradable green certificate (TGC) system, which has been in place since May 2003. To improve the functioning of the TGC market through an increased production base and liquidity, in 2010 it was decided that the market should be expanded to include Norway, starting in January 2012. The Swedish-Norwegian TGC system thus became the first multi-national market of this kind in the world.

Under the TGC system, producers of electricity from renewable energy sources (RES-E) are given a tradable green certificate for each MWh of renewable energy 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. This helps RES-E producers recover the extra cost of producing RES-E, compared to conventional electricity generation. The buyers of TGCs are mainly electricity retailers and large energy-intensive firms, which are required to acquire certificates corresponding to a certain percentage of the total consumption of electricity (the so-called percentage requirement). We call these firms TGC obliged parties. The percentage requirement creates a direct link between the electricity market and the TGC market, because what happens in the electricity market has a direct impact in the TGC market and vice versa (see, e.g., Fischer, 2010; Schusser and Jaraitė, 2018).

Several studies have raised concerns about the potential effects of market power in the TGC market. Specifically, the risk is that those electricity producers that have access to the most suitable sites to produce RES-E could become dominating producers of green electricity. This would allow them to exercise market power not only in the TGC market, but also in the electricity market by exercising power in the TGC market. There is also a risk that the withdrawal of a given number of certificates would force a reduction of electricity consumption, affecting electricity prices and the allocation of resources in the power industry (see, e.g., Amundsen and Bergman, 2012). Market power on the supply

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side of the TGC market could also lead to a higher than competitive TGC price, negatively affecting the cost-effectiveness of the system and increasing the financial burden for final electricity consumers (see, e.g., del Río, 2007).

In this paper, we investigate another source of market power: the ownership structure among participants in the TGC market. In the context of our analysis, two types of ownership – common ownership and cross-ownership – could be considered. Common ownership is defined as a situation when firms on one side of the TGC market own (or are owned by) firms that own shares in other companies on the same side of the TGC market. In contrast, cross-ownership is defined as a situation when firms participate on both sides of the TGC market, either directly or indirectly, by owning shares in other firms that directly participate in the TGC market (see, e.g., Ekeberg et al., 2003).

Common and cross-ownership occur frequently in some markets, such as the banking, airlines, and energy-related industries. This is due in part to the increasing popularity of investment funds, which allow investors to diversify their holdings and therefore reduce their exposure to individual firm risks (see, e.g., Vives, 2020). In the Swedish electricity sector, this is also explained by a wave of mergers and acquisitions that took place after the deregulation of the Swedish power market in the late 1990s. At that time, companies with a strong position in electricity generation acquired holdings not only in other electricity generation companies but also in distribution and retailing companies (see, e.g., Amundsen and Bergman, 2002).

Recent theoretical and empirical studies have found that common and cross-ownership may have a detrimental effect on market competition (see, e.g., Schmalz, 2021). This can happen because, under common and cross-ownership, the ultimate owner's objective is to maximize the total profit of the portfolio of shares. It might therefore be in the ultimate owner's interest to compete more or less aggressively to maximize profit, compared to a perfectly competitive firm without ownership links to other firms in the industry. For instance, under common ownership, much like horizontal integration, an ultimate owner holding shares in several competing firms might have an incentive to increase prices. In contrast, under cross-ownership, much like vertical integration, an ultimate owner holding shares in firms at different stages of the supply chain (i.e., RES-E producers and TGC obliged parties) might have an incentive to reduce the price charged to its related upstream companies (i.e., cross-owned obliged parties) to increase their profitability, thus increasing the overall profits of the ultimate owner. Compared to cross-owned TGC obliged parties, non-cross-owned TGC obliged parties might thus be exposed to higher TGC prices and greater TGC price volatility. This risk might deter entry into the electricity supply market and potentially reduce downstream market competition.

This paper focuses on cross-ownership because its actual effects are not well understood. This is despite the importance of cross-ownership in the TGC market. As shown by our analysis, the largest obligation to surrender TGCs falls on energy retailers, many of which are also producers of green electricity. To examine the implications of the ownership structure in the Swedish TGC market, we use detailed ownership and transaction level data for the period 2003–2018. First, we analyze ownership relationships among participants in the TGC market. To determine common and cross-ownership, we map TGC suppliers and obliged parties to their parent company (the so-called global ultimate owner, GUO). This allows us to identify which parent companies participate on one or on both sides of the TGC market. We refer to parent companies that are active on both sides of the TGC market during the period 2003–2018 as *cross-ownership firms.* Parent firms that are active only on one side of the TGC market are called *non-cross-ownership firms.* Second, we determine the extent of cross-ownership on the TGC market and its evolution over time by means of Herfindahl-Hirschman indexes (HHI) of market concentration that account for common ownership on the supply side or the demand side of the TGC market, as well as for cross-ownership on the overall TGC market. Third, we explore the prices paid in the TGC market by linking transactions to ultimate parent firms. We examine whether TGC prices and their variability differ depending on whether transactions occur within or outside cross-owned parent firms. Finally, the integration of the Swedish and Norwegian TGC markets that took place in 2012 was expected to reduce market power and increase competition. Hence, we analyze the implications of this enlargement on market concentration (measured through the HHIs) and TGC prices.

Our paper contributes to several strands of the literature in energy economics and policy. First, it contributes to the evaluation of the outcomes of the first multi-national market of tradable green certificates. Several previous empirical studies have analyzed different aspects of the performance of the Swedish-Norwegian TGC market. These include studies of the market efficiency of the Swedish and Norwegian TGC market (Bergek and Jacobsson, 2010; Linnerud and Simonsen, 2017), interactions between the EU emissions trading system, the Swedish TGC, and the Swedish power market (Schusser and Jaraitė, 2018), and the links between regulatory changes and TGC price volatility (Fagiani and Hakvoort, 2014; Ganhammar, 2021). Our study is, to the best of our knowledge, the first to trace the ownership structure of the Swedish TGC by linking suppliers and obliged parties to their parent firms and to investigate the implications of cross-ownership on market concentration and TGC prices.

Second, our paper contributes to the rapidly growing empirical literature investigating the effects of ownership on market outcomes in different industries. Most studies focus on common ownership, but some recent studies investigate the anticompetitive effects of cross-ownership. Former empirical studies typically find less aggressive price competition and higher markups in markets in which the major competitors are commonly owned (see, e.g., Schmalz, 2018; Azar et al., 2022). Empirical studies on cross-ownership find that, in vertically related markets, upstream firms discriminate in favor of their downstream cross-owned firms by charging lower input prices. For instance, studies by Ojeda (2019) and Colombo et al. (2022) show that cross-ownership between banks and non-bank borrowers causes lower borrowing rates. Such price discrimination might be due to decreased information and monitoring frictions or due to anti-competitive reasons.

Our paper contributes to such literature by investigating the implications of cross-ownership on TGC prices. Cross-ownership in the TGC market is very salient because major RES-E producers are indeed owned by parent companies that are actively engaged in the retailing of electricity. Cross-ownership parent companies both buy and sell in the wholesale electricity market and in the TGC market. Hence, cross-ownership TGC firms have the incentive to exercise market power to increase the costs faced by rival companies, thus increasing the overall profits of the parent company. Our unique data on TGC transactions allows us to identify differences in pricing strategies depending on cross-ownership, and to analyze how these strategies have changed over time in response to changes in the overall market structure of the TGC system.

By using ownership data, we find that the extent of cross-ownership was considerable, especially during the first years of TGC market operation. Nevertheless, based on our constructed HHIs, we conclude that the TGC market was competitive, particularly on the supply side – even after accounting for ownership. However, cross-ownership potentially affected TGC prices, in that the prices of transactions performed by cross-ownership parent firms are significantly lower and less volatile than TGC prices of transactions performed by non-cross-ownership parent firms. Our results also indicate that TGC prices and the price differences between TGC prices of transactions performed by cross-owned and non-cross-owned firms decreased after the enlargement of the Swedish TGC market but only on the supply side of the TGC market.

The paper is organized as follows. Section 2 presents the Swedish TGC system, and explains how its development over time shaped the Swedish TGC market. In Section 3, we provide a taxonomy of cross-ownership and discuss our empirical strategy. Section 4 describes the data and its sources. In Section 5, we investigate the extent of cross-

ownership and its implications for TGC market concentration. We also investigate the relationship between pricing behavior and ownership structure, and the effects of TGC market enlargement on TGC prices. In Section 6, we conclude the paper and provide some policy implications and directions for future research.

2. The Swedish TGC system

The Swedish TGC market is comprised of a supply of TGCs and a demand for TGCs. The size of the demand and supply depends on the annual percentage requirement – an obligation of electricity retailers and energy-intensive industries to buy a certain share of TGCs in relation to their total electricity sales or consumption every year. Changes in the percentage requirement (and changes in electricity sales or consumption) directly affect the demand for TGCs and consequently the supply of TGCs. Fig. 1 shows that the percentage requirement was 7.4 percent in 2003 and 29.9 percent in 2018. It will be 27.6 percent in 2035, which is when the system expires. From 2018 onward, about one-third of electricity consumption in Sweden should be produced from renewable energy sources.

The increasing demand for TGCs is very well reflected on the supply side of the TGC market. TGC supply is determined by the number of issued TGCs. Issued TGCs, in turn, are directly and positively related to renewable energy generation that is eligible to receive TGCs. However, not all issued TGCs are expected to appear on the market for sale during a particular year, because renewable power producers have the right to bank TGCs and release them in the following years. Fig. 2 shows issued TGCs for each renewable energy technology, cancelled TGCs for compliance, and accumulated banked TGCs for each year. For instance, in 2003, the number of banked TGCs was about 2.1 million, and it has increased since then. This means that, since the first year of the TGC system, there has been a considerable surplus of TGCs in the market. To some extent, the surplus of TGCs has been reflected in TGC prices.

Fig. 3 shows the dynamics of average register TGC price for the period from March 2004 until March 2019. TGC price was slightly falling until 2006, but from 2007 to 2008 it was rising, plateauing at just above SEK 300 in 2009. In 2010, TGC price started falling again and has been moving between SEK 70 and SEK 200 ever since. The mean price for the entire period under consideration is around SEK 200 per certificate. What is surprising is that the average price of TGCs has been rather high, even though there has been a considerable surplus of TGCs in the system since its launch. To the best of our knowledge, there is no study explaining this high price level. In hindsight, the price was clearly too high, considering that, at the beginning, the number of TGCs was generated by existing power generating plants; this meant that most of their production was already competitive, or at least needed far less support than entirely new production plants.

Finally, Fig. 4 shows how prices of TGCs compare to average day-ahead market prices of electricity (before taxes). It is evident that, during some periods, the price of TGCs was as high as the market price of electricity, and in some periods TGC prices were significantly higher than the market price of electricity. On average, TGC prices constituted about 66 percent of electricity prices. In other words, since the start of the TGC system, a tradable green certificate has become an asset, which has maintained its value despite the surplus of TGCs in the system.

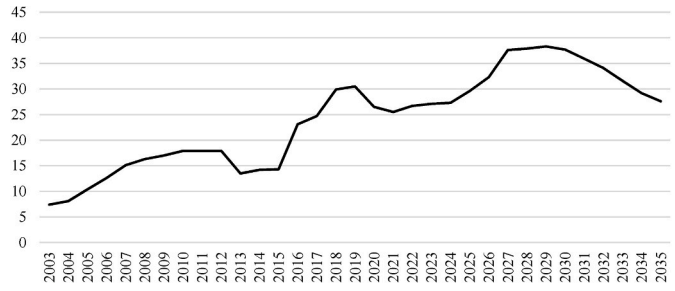

Fig. 1. Percentage requirement, 2003–2035.
Source: https://www.energimyndigheten.se/fornybart/elcertifikatsystemet/om-elcertifikatsystemet/kvotnivaer/, last updated on January 8, 2021.

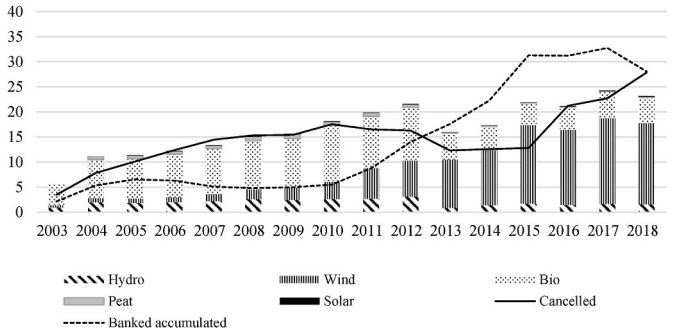

Fig. 2. Issued, cancelled and banked TGCs in millions, 2003–2018. *Notes*: The numbers of issued and cancelled certificates were retrieved from the Swedish Energy Agency's electricity certificate register Cesar (accessed October 2020). The year 2003 corresponds to the period May–December 2003.

Fig. 3. Monthly average register TGC price in SEK, March 2004–March 2019. *Source*: The figure was produced by the authors using TGC price data from Cesar register.

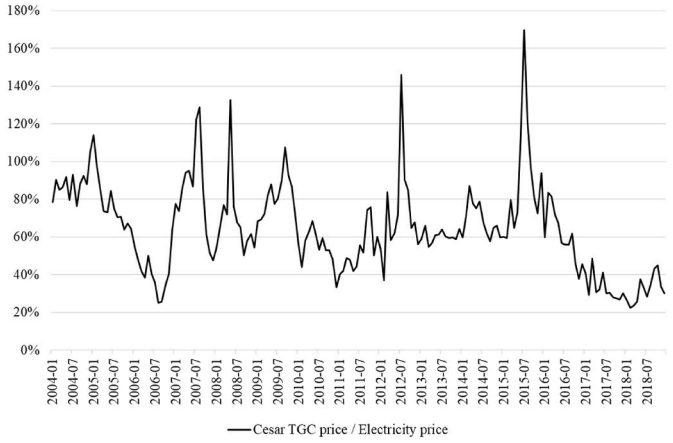

Fig. 4. TGC price compared to market electricity price, January 2004–December 2018. *Source*: The figure presents the ratio of the monthly average TGC price to the monthly average day-ahead market price of electricity (before taxes). The figure was produced by the authors using TGC price data from Cesar register and data on day-ahead electricity prices from the Swedish Energy Agency.

3. Empirical strategy

In this section, we briefly discuss our empirical strategy. First, we provide the taxonomy and examples of cross-ownership and explain how

we use this taxonomy to analyze the ownership structure in the TGC market. Second, we discuss how we investigate market concentration in the TGC market. Third, we explain how we analyze the prices paid in the TGC market by linking transactions to ultimate parent firms.

3.1. Taxonomy of cross-ownership

Cross-ownership denotes the situation where a parent firm – also the so-called global ultimate owner – participates on both sides of the TGC market either directly (by directly operating on both sides of the TGC market) or indirectly (by owning shares in other firms that directly participate in the TGC market).

Fig. 5 provides some examples of cross-ownership. In panel A, for instance, parent Firm A participates directly on the demand side and the supply side of the TGC market. In panels B and C, the parent company (corresponding to Firm C and Firm D, respectively), participates on both sides of the TGC market indirectly via their ultimate ownership of other firms that participate on the supply and demand sides of the TGC market. For instance, in panel C of Fig. 1, the parent company D owns three firms – Firm A, Firm B, and Firm C. Firm B directly operates on the supply side of the TGC market, while Firm C owns Firm A, which is active on the demand side of TGC market.

Cross-ownership gives the parent company control over its owned companies, allowing the coordination of the activities of companies that are active in the TGC market. We can thus expect that parent companies owning companies on both sides of the TGC market might utilize different pricing strategies for TGCs traded within the holding versus those TGCs traded outside the holding. Following the literature on vertical integration, we hypothesize that TGCs traded within the holding will be traded at lower prices than those TGCs that are traded outside the holding.

To perform ownership analysis, we proceed in the following way. First, we map as many TGC facilities and obliged parties as possible to their parent company. The technicalities of this procedure and employed data sources are described in Section 4. Second, we identify cross-ownership firms and analyze market concentration in the TGC market.

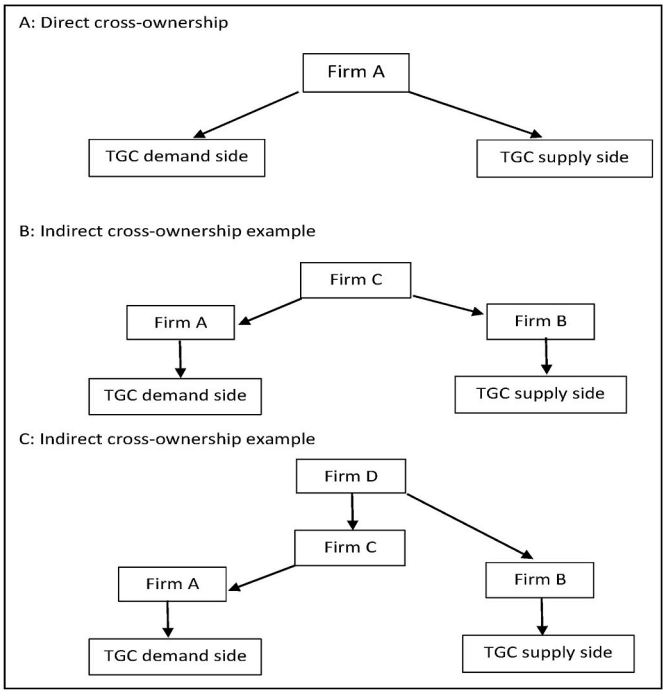

Fig. 5. Examples of cross-ownership.
Source: The figure is drawn by the authors.

3.2. Measuring market concentration

The most common way to measure market concentration is to calculate the market shares of the largest actors. Market shares are usually calculated as each player's share of sales in the market either by volume or value. In the electricity market, the market shares are ordinarily calculated as each player's part of the total production or installed capacity in the relevant markets. In the TGC market, the best approach to measure market shares is by using data on issued and obliged TGCs, as this is a common metric that is relevant for both sides of the TGC market. Additionally, we consider the share of RES-E capacity owned by cross-ownership firms.

Another well-known concentration index is the HHI. The HHI is defined as the sum of the squares of market shares of all the firms in the relevant market. The HHI will vary between 0 (an atomistic market) and 10 000 (monopoly) if market shares are measured in percentages (equivalently between 0 and 1 if market shares are measured as decimals). Since the shares are squared, the HHI will put more emphasis on large than small firms. Antitrust agencies generally consider markets in which the HHI is between 1500 and 2500 points to be moderately concentrated, and consider markets in which the HHI is in excess of 2500 points to be highly concentrated.

To quantify the effect of cross-ownership on market concentration, we calculate three types of HHIs: ownership unadjusted HHI, common-ownership adjusted HHI_a, and cross-ownership adjusted HHI_{ca}. HHI and HHI_a are separately calculated for the supply and demand sides by using the issued TGCs and obliged TGCs, respectively. In contrast, HHI_{ca} is calculated for the entire TGC market, accounting for market concentration on both the supply and demand sides by summing the squares of the market shares measured as the ratio of the cross-ownership firm's total TGCs (issued and obliged) to the total number of TGCs (issued and obliged) in the market. If common ownership increases the market concentration on the supply side, we expect the value of the HHI_a for the supply side to be larger than the value of the ordinary HHI. The same applies to the demand side.

3.3. Analyzing TGC prices

The final stage of the empirical analysis is to analyze the prices paid in the TGC market by linking transactions to ultimate parent firms. The goal of this analysis is to investigate whether the pricing behavior of cross-ownership firms differ from that of non-cross ownership firms. First, we statistically compare the average TGC prices between cross-ownership and non-cross ownership firms. We are interested in whether average TGC prices differ according to the direction of the transaction (selling vs. buying) and the receiver of the transaction ("within trading," which is trading with other firms owned by the same parent company, and "outside trading," with other firms outside the parent company). Second, we analyze the differences in TGC price variability between non-cross-ownership firms and cross-ownership firms. As in the case of average TGC prices, we compare price variability according to the ownership structure (cross-ownership vs. non-cross-ownership), the direction of the transaction (selling vs. buying), and the receiver of the transaction (within parent company vs. outside parent company).

To further investigate the relationship between cross-ownership and TGC prices, as well as the effects of the enlargement of the TGC market on TGC prices on the Swedish side of the market, we make use of a regression-based analysis of TGC prices. Our basic identification strategy relies on distinguishing behavior between cross-ownership firms and non-cross-ownership firms before and after the enlargement of the TGC market. We estimate the regression specified in equation (1) for two reasons. The first reason is to determine whether prices of sold or purchased TGCs have changed over time, especially after the enlargement of the TGC market in January 2012. Second, we want to further investigate whether prices of TGCs sold or purchased by cross-ownership

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

Variable name	Variable description	Measurement unit	Data source
Capacity	Installed electric capacity of TGC facility. For some facilities (e.g., hydro) not all of this capacity was eligible for receiving TGCs. In some cases, the installed capacity of one facility could have multi-ownership.	MW	SEA
Type of capacity	RES type of installed electric capacity of TGC facility. Eight types of RES capacity are provided: onshore wind, offshore wind, solar power, wave power, hydropower, CHP, industrial power, other.		SEA
Received TGCs	TGCs received by a particular TGC facility every year during the period 2003–2018.	In thousands TGCs or millions of TGCs	SEA
Global Ultimate Owner (GUO)	Firm parent that directly/indirectly owns a particular TGC facility or/and an obliged party.		Orbis Europe
Obliged TGCs	TGCs that had to be surrendered to the regulator on annual basis by a particular obliged party during the period 2003–2018.	In thousands TGCs or millions of TGCs	SEA
Category of obliged party	This shows on which basis a particular obliged party was included in the TGC system. Obliged parties are categorized into three groups: electricity suppliers, electricity users (producers/importers), and electricity-intensive industries		SEA
Price of TGC	Price at which one TGC was traded, transaction level data	In SEK	Cesar
Volume of TGCs transferred	Volume of TGCs transferred from one Cesar account to another, transaction level data	Number of TGCs	Cesar
Annual average weighted price of TGC at GUO firm level	Volume weighted average price of TGC traded by a particular GUO firm within a particular year	In SEK	Cesar and authors' calculations
Annual cumulative net holdings of TGCs at GUO level	Annual cumulative net holdings of TGCs at GUO firm level are calculated by accumulating annual net holdings of TGCs at GUO firm over time. Annual net holdings of TGCs are calculated as the difference between received/bought/imported TGCs and cancelled/sold /exported TGCs by GUO firm: received TGCs + bought TGCs + imported TGCs - cancelled TGCs - sold TGCs - exported TGCs.	In thousands TGCs	Cesar and authors' calculations

firms are different from TGC prices sold or purchased by non-cross-ownership firms. This is important because the descriptive analysis does not control for unobserved parent-company characteristics and year effects. To perform this analysis, we aggregate transaction level TGC prices to annual average volume weighted TGC prices of sold or purchased TGCs for every parent company during the period 2003–2018.

The regression is specified as follows:

$$p_{it} = \alpha_i + \beta d_t + \gamma d_t \times CO_i + \varepsilon_{it}, \quad (1)$$

where p_{it} is an annual average volume-weighted price of TGCs sold or purchased by parent company i in year t; α_i is the fixed effect of parent company i in the fixed-effect regression specification; d_t are the yearly fixed effects, with 2011 as the reference year; CO_i is a dummy variable that is equal to one for the cross-ownership firms and zero otherwise; and ε_{it} is an error component. The coefficient γ of the interaction term between the year fixed effects and the cross-ownership indicator, $d_t \times CO_i$, will capture the difference in TGC prices between cross-ownership and non-cross-ownership firms over time. We will measure the specified regression for five different sets of TGC prices: (1) prices of all TGCs sold, (2) prices of TGCs sold outside the parent company, (3) prices of all TGCs purchased, (4) prices of TGCs purchased outside the parent company, and (5) prices of TGCs traded within the parent company.

4. Data

This study mainly relies on three data sources: (1) public data provided by the Swedish Energy Agency (SEA), (2) data from the Orbis Europe database, available by subscription from Bureau van Dijk (BvD), and (3) confidential Cesar registry data on TGC transactions managed by the SEA. The SEA provided us with data on TGC facilities, obliged parties, and their major characteristics, as well as Cesar transaction data, while the Orbis Europe database was used to retrieve ownership information.

Table 1 describes the main variables used in the analysis, their measurement units, and data sources. In what follows, we describe our data in more detail.

4.1. Data about TGC market participants

The supply side of the TGC market consists of private and firm-owned facilities that produce electricity from the following renewable energy sources: onshore and offshore wind power, solar energy, wave energy, geothermal energy, biofuels, peat used in CHP plants, and hydropower.[1] Facilities that started operation after the introduction of the TGC system are entitled to receive TGCs for 15 years, but no later than the end of 2035.[2] Facilities that were put into operation before the introduction of the TGC system were entitled to receive TGCs until the end of 2012. Some renewable facilities that received state aid to support their conversion or construction were entitled to receive TGCs until the end of 2014.

The list of TGC facilities provided by the SEA contains information about each facility's identification number, name, address where the facility is located, owner (or owners) firm registration number (or numbers), installed capacity, type of renewable capacity, and annual received TGCs. According to this data, the number of TGC facilities has been growing since the start of the TGC system, from 1 589 unique TGC facilities in 2003 to 10 681 unique TGC facilities in 2018. In our analysis, we focus on firm-owned RES-E facilities.

The data on obliged parties contains information about each obliged party's name, firm registration number if an obliged party is a firm, category according to which an obliged party has an obligation to surrender TGCs to the regulator, and the number of obliged and surrendered TGCs. According to this data, the number of obliged parties has been much smaller than the number of TGC facilities. There were 447 firms and 628 firms that had to surrender some positive amount of TGCs in 2003 and 2018, respectively.[3]

From the Orbis Europe database, we extracted information about each firm's current parent or so-called GUO. In line with the Orbis Europe database, GUO denotes the entities ultimately controlling a company, which is to say that a GUO controls at least 50.01% of all corporate levels below it. The GUO itself does not have a shareholder that controls more than 50.01% of its shares. One exception is if the company is controlled by the government or a particular municipality.

[1] Some additional restrictions apply for biofuel-based facilities and hydropower based facilities (for more information, see Energimyndigheten (2012)).

[2] Toward the end of 2021, it was agreed to close down the Swedish-Norwegian TGC system at the end of 2035. This means that the system was closed to new participants as of 1 January 2022.

[3] There are also several private persons who are obliged to surrender TGCs to the regulator every year. We excluded private entities from the analysis.

In this case, we define the GUO to be the penultimate level of the company's ownership structure, given that the government or a particular municipality represents the ultimate level of ownership. Furthermore, we will assume that a firm is considered to be an ultimate owner itself if it has no identified shareholders or if its shareholders' percentages are not known. This is the definition used by the Orbis Europe database.

4.2. Transaction data

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 the Swedish account management system 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.

Cesar registers all movements of TGCs across different accounts. Transfers are grouped into six types: (1) issuance of TGCs for firms that produce electricity from eligible renewable energy sources, (2) cancellation of TGCs by firms that must fulfill TGC quota, (3) internal TGC transfers between accounts of the same account holder, (4) external TGC transfers between accounts of different firms, (5) TGC exports to firms in Norway, and (6) TGC imports from firms in Norway. Because transfers of types 1–3 record movements of TGCs within the same firm, these transfers do not have price tag. In contrast, types 4–6 record movements between different firms. Hence, these transfers record sales or purchases of TGCs and have a price tag (see Table 2).

Our analysis focuses only on the trading activity of Swedish firms. This is because TGC transfers between solely Norwegian accounts are not recorded in Cesar but in the Norwegian TGC register NECS, to which we could not gain access. Furthermore, recall that transactions in a given year do not need to match the issuance of TGCs, because account holders can accumulate unused TGCs over time. This means, for instance, that TGC obliged parties can allocate unused TGCs for future compliance periods, or that firms that receive TGCs can keep their TGCs in their accounts and wait for a better price.[4]

Table 2 shows that external transfers comprise most of the total transactions during the period 2003–2018, followed by internal transfers between accounts of the same account holder. External transfers account for 76.9 percent of the total transactions, which is more than three times the number of internal transfers (21.8 percent of the total transactions). In contrast, the share of exports and imports of TGCs was relatively small, respectively 0.5 percent and 0.3 percent. This is to say, Swedish account holders are net exporters of green certificates, which is consistent with the relatively small share of annual production of TGCs by Norwegian firms (see, e.g., Linnerud and Simonsen, 2017).[5]

The average price of TGC traded externally in Sweden during the period 2003–2018 corresponds to SEK 198.2 (approximately €20), which is well in line with the average mean price presented in Fig. 3.

5. Ownership structure and TGC prices

5.1. Ownership in the TGC market

5.1.1. Supply side

We start by analyzing ownership on the supply side of the Swedish TGC market. During the period 2003–2018, there were 5 481 unique firm-owned facilities that could receive TGCs for producing RES-E. The analysis of ownership of these facilities reveals that about 72 percent of these facilities (3 922 facilities) were ultimately owned by private firms of either Swedish or foreign origin, 19 percent (1 049 facilities) were owned by various Swedish municipalities, and the remaining facilities were owned either by the Swedish Government (208 facilities), the Norwegian Government (201 facilities), or the Finnish Government (101 facilities).

From panel (a) in Fig. 6, it is evident that firms whose parents are the Swedish government owned most of the RES-E installed capacity that has been included in the TGC system. However, not all this capacity has been receiving TGCs, even if it has been utilized fully. This is especially true for old hydropower capacity, of which only a small percentage has been eligible for receiving TGCs. This fact is reflected in panel (b) of Fig. 6, where it is evident that firms owned by the Swedish Government received only about 3–8 percent of all issued certificates per year during the period of 2003–2018.

Fig. 6 also reveals that the market share of facilities owned by private firms have been increasing in terms of installed RES-E capacity and received TGCs. For instance, in 2018, private firms owned 3037 unique facilities out of 5 481, 37 percent of all RES-E installed capacity covered by the TGC system and received 70 percent of all issued TGCs during that year.

5.1.2. Demand side

First, we categorize TGC obliged parties into three groups: electricity suppliers, electricity users (producers/importers), and electricity-intensive industries.[6] Fig. 7 shows that the highest obligation to surrender TGCs to the regulator has been falling on electricity suppliers. This obligation has been steadily increasing since the start of the TGC system, following the increases in the renewables percentage requirement. In total, there have been about 170–180 electricity suppliers. Energy-intensive industrial firms and electricity producers/importers have been obliged to surrender similar amounts of TGCs.

Second, regarding ownership on the demand side, the data indicates that, during the period 2003–2018, about 87 percent of 1 641 unique firms obliged to surrender TGCs were ultimately owned by private firms of either Swedish or foreign origin, 12 percent (199 firms) were owned by Swedish municipalities, 16 obliged firms were owned by the Swedish Government, and one by the Norwegian Government (see panel a in Fig. 8). Obliged parties owned by private firms were obliged to surrender the largest share of TGCs (44–48%). Obliged parties owned by Swedish municipalities were responsible for surrendering about 37–39 percent of all obliged TGCs, while the firms owned by the Swedish Government had to surrender about 15–17 percent of all obliged TGCs (see panel b in Fig. 8).

5.1.3. Supply and demand side: cross-ownership firms

In our dataset, we could identify at most 221 parent companies that were active on both the supply and demand sides of the TGC market at some point over the period 2003–2018. In Tables 3 and 4, we report how

[4] TGCs are often transferred to the TGC obliged party's account in December or March for compliance with the regulatory cycle that ends on the 1st of April.

[5] As of January 2017, the Swedish-Norwegian TGC scheme had contributed to investments in RES-E accounting for 17.8 TWh per year, out of which only 3.0 TWh were due to Norwegian hydropower, and 0.4 TWh were due to Norwegian wind power.

[6] According to the regulation, obliged parties are grouped in more categories: (1) professional electricity suppliers who sell electricity to other users, (2) electricity users who 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 who use imported electricity or buy electricity on the Nordic electricity market, (4) electricity producers who 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 obliged party categories.

Table 2
Description of transaction data, 2003–2018.

Type of transaction	Description of transaction	No. Of transactions	% of transactions	Average price of TGC, SEK	Average volume, no. Of TGCs
Compliance related transactions					
Issuance of TGCs	Initial issuance of TGCs for firms that own RES facilities that are entitled to receive TGCs.	239 097	95.1	–	1 018
Cancellation of TGCs	Cancellation of TGCs that are surrendered for compliance by firms that have TGC quota obligation.	12 360	4.9	–	19 131
Market related transactions					
Internal transfer of TGCs	Internal transfer of TGCs within a particular firm.	86 127	21.8	–	2 262
External transfer of TGCs	External transfer of TGCs between two different firms.	303 315	76.9	198.2	1 684
Export of TGCs to Norway	Export of TGCs from firms in Sweden to firms in Norway, relevant from January 2012.	3 326	0.8	152.5	13 477
Import of TGCs from Norway	Import of TGCs from firms in Norway to firms in Sweden, relevant from January 2012.	1 892	0.5	157.4	17 452

Source: Cesar registry data and the authors' calculations.

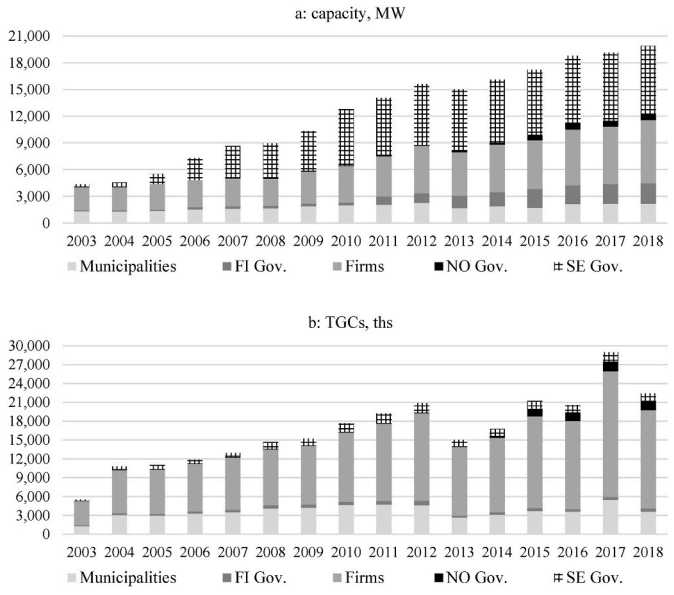

Fig. 6. Ownership of TGC facilities: capacity and received TGCs.
Source: The figure was produced by the authors using data from the Orbis Europe database and the Swedish Energy Agency.

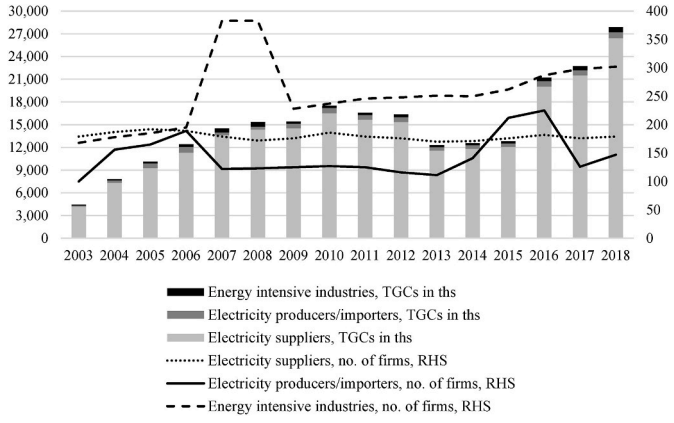

Fig. 7. Obliged parties: number of firms and obliged TGCs in thousands.
Source: The figure was produced by the authors using data provided by the Swedish Energy Agency.

many of these companies were active either on the supply or on the demand side each year.

Table 3 shows how many facilities and firms on the supply side were owned by cross-ownership firms. In 2003, for instance, we could identify 126 cross-ownership firms that owned 357 facilities (out of 1 254). In 2018, this number increased to 221 cross-ownership firms that owned 876 facilities (out of 4 185). In other words, cross-ownership firms owned about 20 percent of RES-E generating facilities that were eligible to receive TGCs. However, the market share of these cross-ownership firms is much larger once we consider their RES-E capacity and received TGCs. As shown in Table 3, in 2003, these firms owned about 84 percent of firm-owned RES capacity and received about 82 percent of firm-received TGCs. Over time, the dominance of these firms has decreased significantly; from 2015 to 2018, they owned only about 20 percent of capacity and 35 percent of TGCs.

Table 4 shows how many firms on the demand side were owned by cross-ownership firms. It also shows how many TGCs these firms were obliged to surrender every year compared to all surrendered TGCs. For instance, in 2003, we could identify 122 cross-ownership firms that owned 132 TGC obliged firms and had to surrender about 32 percent of all obliged TGCs. In contrast to what is observed on the supply side, on the demand side the number of cross-ownership firms and their share of obliged certificates has been increasing over time. In 2018, for instance, 199 of these firms owned 245 obliged entities, which had to surrender about 46 percent of all obliged TGCs.

In summary, the analysis of cross-ownership reveals that the supply and demand sides of the TGC market are strongly interlinked via ownership. Although there are many firms on each side of the market, there is no doubt that the existence of parent companies active on both sides of the TGC market has played an important role in shaping the outcomes of the Swedish TGC market. This was especially so during the first years, when cross-owners owned a considerable share of the TGC market – either on the supply side or on the demand side.

5.2. HHIs and ownership

Fig. 9 displays the values and evolution of the HHI, HHI_a, and HHI_{ca} over time. The results indicate that market concentration in the entire TGC market has been low – even after accounting for cross-ownership – and it has decreased over time. Over the period 2003–2018, the value of HHI_{ca} has ranged between 330 and 184, with an average equal to 266 (see Fig. 9). We observe, however, that market concentration on the demand side is larger than market concentration on the supply side. Furthermore, while market concentration on the supply side has decreased significantly over time, (maximum HHI_a equal to 503 in year 2003, and average HHI_a equal to 187 over the period 2012–2018), the level of market concentration on the demand side has remained

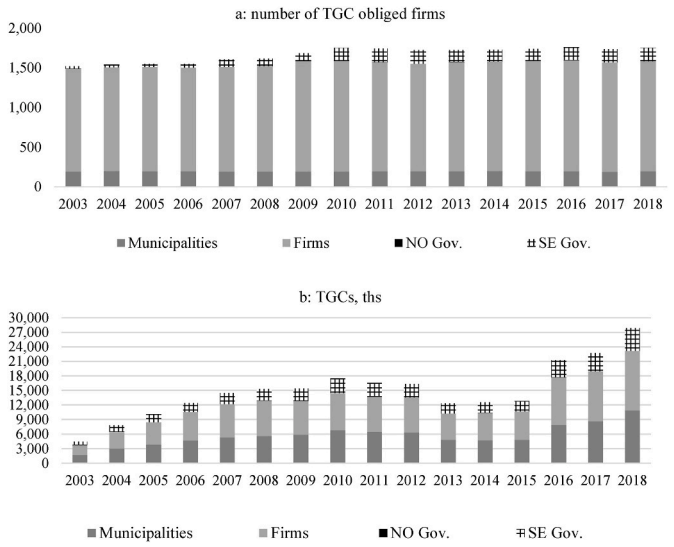

Fig. 8. Ownership of obliged parties: obliged TGCs in thousands and number of obliged parties.
Source: The figure was produced by the authors using data from the Orbis Europe database and the Swedish Energy Agency.

Table 3
Cross-ownership firms on the supply side of the TGC market.

Year	#Cross-ownership firms	#RES-E facilities of cross-ownership firms	#RES-E firms of cross-ownership firms	% of firm-owned RES-E capacity of cross-ownership firms	% of firm TGCs received by cross-ownership firms
2003	126	357	138	84.1	82.4
2004	140	382	154	79.4	81.9
2005	145	393	159	70.0	82.6
2006	146	403	159	56.9	82.2
2007	153	419	167	48.4	79.9
2008	159	441	174	44.7	76.3
2009	174	480	190	43.9	75.1
2010	179	508	195	37.4	73.8
2011	184	549	201	33.9	64.6
2012	188	599	206	33.0	61.2
2013	134	412	141	23.7	43.2
2014	150	482	158	22.7	41.2
2015	162	528	176	20.0	34.5
2016	177	633	197	21.2	34.8
2017	201	829	244	21.0	46.4
2018	221	876	281	21.0	34.8

Source: The table was produced by the authors using data from the Orbis Europe database and the Swedish Energy Agency.

relatively stable (average HHI_a equal to 550 over the period 2003–2010 and equal to 507 over the period 2012–2020).

Finally, it is evident that the effect of common-ownership on the value of the HHI is much more salient on the supply side than on the demand side (HHI_a is approximately 42% larger than HHI for the supply side, and only 5% larger for the demand side). Furthermore, for the supply side, the percent differences between the magnitude of the HHI_a and HHI are larger for the period 2012–2018 than for 2003–2010 (46% vs. 40% larger, respectively).

Amundsen and Bergman (2002) discussed the potentially negative effect of common ownership as a source of market power in the Nordic power market. They argue that the integration of the power markets in Norway and Sweden in 1996 significantly constrained the major power companies' ability to exercise market power within their national borders. However, mergers and reciprocal acquisition of shares have reduced the number of independent players on the Norwegian-Swedish

Table 4
Cross-ownership firms on the demand side of the TGC market.

Year	#Cross-ownership firms	#TGC obliged firms of cross-ownership firms	% of obliged TGCs by cross-ownership firms
2003	122	132	31.9
2004	134	151	32.5
2005	145	163	47.3
2006	144	163	45.4
2007	140	165	43.4
2008	142	168	42.2
2009	137	158	44.2
2010	144	166	44.4
2011	149	169	43.6
2012	145	168	43.9
2013	141	165	43.8
2014	147	173	45.7
2015	163	192	44.4
2016	174	206	43.9
2017	179	211	44.1
2018	199	245	45.6

Source: The table was produced by the authors using data from the Orbis Europe database and the Swedish Energy Agency.

power market over time. There is a risk that partial ownership relationships between generators increase horizontal market power and thus the market price of electricity. Our analysis shows that the same risk applies to the TGC market, and that market integration is not a guarantee against market power under common and cross-ownership relationships.

In summary, if TGC market concentration is analyzed without regard to ownership relationships, this could lead to underestimation of market power. Even if our analysis does not show that the Swedish TGC market is not competitive, we have shown that common and cross-ownership relationships in the TGC market are significant.

5.3. Cross-ownership and TGC prices

5.3.1. Average TGC prices

Table 5 provides the descriptive statistics of external transfers of TGCs by firms whose parent company was active on both sides of the TGC market, and by firms whose parent company was active only on one side of the TGC market (cross-ownership vs. non-cross-ownership). TGC transactions are classified according to the direction of the transaction (selling vs. buying), the receiver of the transaction ("within trading," which is trading with other firms owned by the same parent company, and "outside trading," with other firms outside the parent company), and the annual net cumulative holdings of TGCs at the parent company level. For each subgroup, we present the summary statistics on the number of TGC transactions performed, the average TGC price, the standard deviation of TGC prices, and the average volume of TGCs

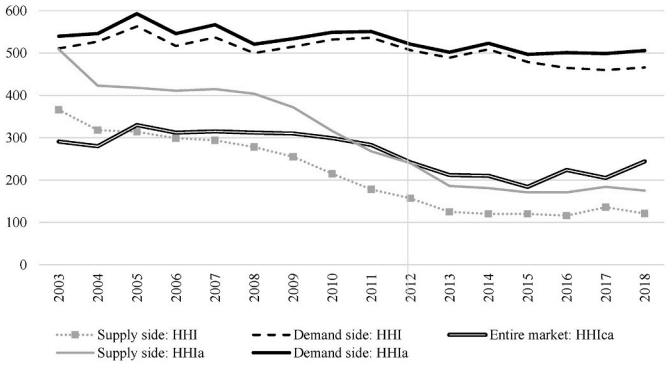

Fig. 9. HH indices for the TGC market over the period 2003–2018.
Source: The figure was produced by the authors using data from the Orbis Europe database and the Swedish Energy Agency.

Table 5
Descriptive statistics of TGC transactions by ownership, 2003–2018.

		Selling transactions				Buying transactions			
		# of transactions	Mean price	S.D. price	Average # of TGCs	# of transactions	Mean price	S.D. price	Average # of TGCs
By cross-ownership firms	**Within trading**	**3 444**	**189.9**	**73.3**	**9 838**	**3 444**	**189.9**	**73.3**	**9 838**
	net short position	3 080	191.1	76.1	9 998	3 080	191.1	76.1	9 998
	net long position	364	180.5	41.4	8 489	364	180.5	41.4	8 489
	Outside trading	**41 755**	**198.6**	**70.1**	**4 517**	**232 605**	**201.1**	**74.8**	**988**
	net short position	11 789	203.4	72.9	6 124	222 656	201.6	74.9	883
	net long position	29 924	196.6	69.0	3 883	8 343	186.1	77.4	3 933
By non-cross-ownership firms	**Within trading**	**1 617**	**200.3**	**80.8**	**14 029**	**1 617**	**200.3**	**80.8**	**14 029**
	net short position	911	186.4	64.1	19 730	911	186.4	64.1	19 730
	net long position	706	218.1	95.3	6 672	706	218.1	95.3	6 672
	Outside trading	**256 499**	**198.3**	**74.3**	**1 036**	**65 649**	**188.3**	**68.7**	3 421
	net short position	8 009	203.7	70.0	10 587	40 779	197.5	71.9	3 362
	net long position	247 552	197.9	74.4	703	23 683	170.9	58.9	3 388

Source: The table was produced by the authors using data from Cesar registry.

traded.

Most TGC transactions performed by cross-ownership firms are outside buying transactions performed by parent companies with net short cumulative TGC positions. By analogy, most TGC transactions performed by non-cross-ownership firms are outside selling transactions performed by parent companies with net long cumulative TGC positions (see Table 5). This is consistent with the fact that, during some years, cross-ownership firms held a larger share of total TGC obligations compared to the share of TGCs that they received (see Tables 3 and 4). In other words, cross-ownership firms were "short" in total, and had to source the TGC market to comply with their TGC obligations.

Furthermore, we find that cross-ownership firms traded TGCs at an average lower price when trading within the parent company than when trading outside the parent company (SEK 189.9 vs. SEK 198.6 for sold TGCs, and SEK 189.9 vs. SEK 201.1 for TGCs bought). This finding is in line with our hypothesis that firms that are owned by cross-ownership firms charge a lower TGC price to cross-owned obliged parties than the price they charge to competing TGC firms. By charging a low price to cross-owned firms, the parent company can increase profits in upstream markets, and potentially increase the rival's costs in complying with the TGC quota.

In contrast, non-cross-ownership firms traded TGCs at a higher average price when trading "within" than when trading "outside" the parent company (SEK 200.3 vs. SEK 198.3 for TGCs sold, and SEK 200.3 vs. SEK 188.3 for TGCs bought). In Table A1 of Appendix, we present statistical tests confirming that the differences in average TGC prices described so far are statistically significant (except for the difference between sold "within" TGC prices and sold "outside" TGC prices of non-cross-ownership firms).

We also find that within trading took place at an average lower price for cross-ownership firms than for non-cross-ownership firms (SEK 189.9 vs. SEK 200.3). This difference in TGC prices is statistically significant (see Table A2 in Appendix). Interestingly, we do not find a statistical difference between cross-ownership and non-cross ownership firms in prices of TGCs sold "outside" the parent company (SEK 198.6 vs. SEK 198.3).

Finally, when comparing prices of TGCs bought by cross-ownership firms and non-cross ownership firms outside the parent firm, we find that cross-ownership firms bought TGCs at statistically significantly higher prices, on average, than non-cross-ownership firms (SEK 201.1 vs. SEK 188.3). All in all, these descriptive findings give some support to our belief that cross-ownership firms had no power to affect "outside" TGC prices on the TGC market, but could possibly affect "within" TGC prices.

5.3.2. *TGC price variability*

As in the case of average TGC prices, we compare price variability according to the ownership structure (cross-ownership vs. non-cross-ownership), the direction of the transaction (selling vs. buying), and the receiver of the transaction (within parent company vs. outside parent company). Fig. 10 presents the box plots of TGC prices for each year during the period 2003–2018 across these dimensions. Additionally, Tables A1-A2 in Appendix summarize the test on the equality of standard deviations of TGC prices during the period 2003–2018 that are presented in Table 5.

First of all, by simple eyeballing, we observe that – regardless of the ownership structure and the direction of the transaction – there is large range of variation in TGC prices for each year during the period 2003–2018. Across cross-ownership firms, we observe that the variation of TGC prices was lower for transactions performed within the parent firm than for transactions performed outside the parent firm. The statistical tests on the equality of standard deviations of TGC prices traded during the period 2003–2018 confirm this observation, but only in the case of prices of purchased TGCs (see Table A1 in Appendix).

When we analyze the differences in TGC price variability between non-cross-ownership firms and cross-ownership firms, we find that non-cross-ownership firms were selling TGCs at prices with higher variability than cross-ownership firms. This finding applies for both within and outside transactions (see Table A2 in Appendix A). In contrast, for prices of purchased TGCs, we observe the opposite pattern – cross-ownership firms were buying TGCs from outside at prices with higher variability than the prices faced by non-cross-ownership firms (see Table A2 in Appendix).

All in all, the analysis of TGC price variability further supports our expectations that TGC prices vary across firms of different types of ownership, and that cross-ownership firms experienced lower TGC price

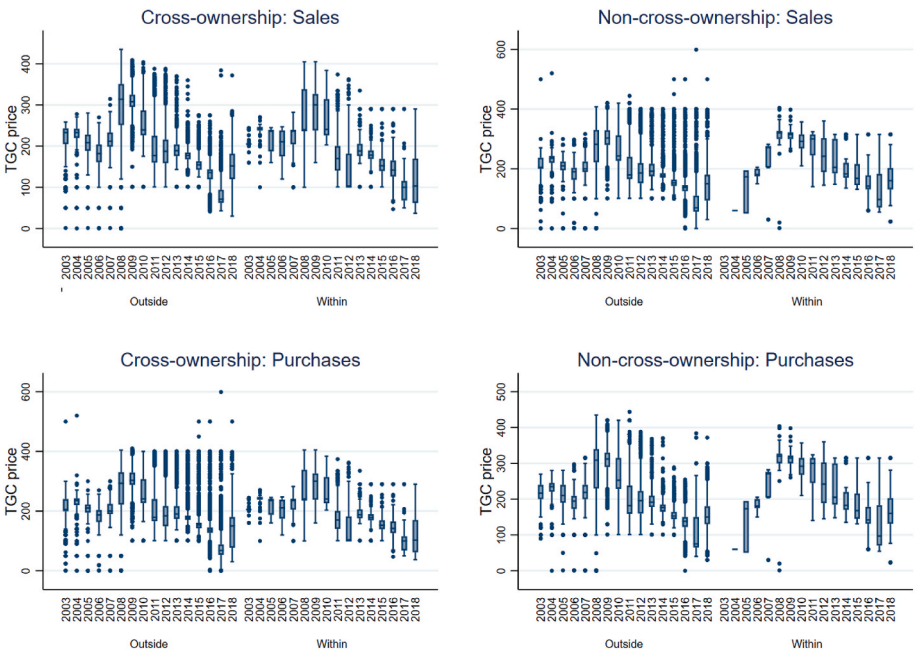

Fig. 10. Distribution of TGC prices over the period 2003–2018.
Source: The figure was produced by the authors using data from Cesar registry.

variability when trading within the parent firm.

5.4. The effects of cross-ownership and market enlargement on TGC prices: regression analysis

The results from the regression analysis are presented in Table 6. First, consistent with our initial expectations, we find that prices of TGCs sold and purchased decreased after 2011, although the decrease in the purchase price for TGCs came with a delay of two years. This decrease in TGC prices can be attributed to the enlargement of the TGC market by including Norway from January 2012, but also to other unobservable time-varying factors, which are not captured in our data.

Moreover, we find that, after controlling for parent-company-fixed and year-fixed effects, cross-ownership firms in general sold TGCs at higher prices than non-cross-ownership firms, especially during the first years of the TGC market (column 1 in Table 6). This difference in prices can be attributed to TGCs sold outside the parent company, which corresponds to the bulk of the sales (column 2 in Table 6). On the other hand, cross-ownership firms bought TGCs at lower prices than non-cross-ownership firms during the entire period under consideration, except the year 2016 (column 3 in Table 6). As in the case of sales of TGCs, this difference is attributed to TGC purchases outside cross-ownership firms (column 4 in Table 6). However, we find no statistically significant differences between cross-ownership and non-cross-ownership firms in prices of TGCs transferred within parent companies, except for the year 2008 (column 5 in Table 6).

Interestingly, the effect of cross-ownership on the prices of externally purchased TGCs is more salient than the effect on the prices of externally sold TGCs (columns 2 and 4 in Table 6). In case of purchased TGCs, this holds even after the enlargement of the TGC market. This pattern could potentially be explained by the dominant position of cross-ownership firms on the demand side of the TGC market since, as shown in Table 5, most cross-ownership firms were "short" in total, and had to buy TGCs outside the parent company to comply with their TGC obligations.

Although these regression results lack causal interpretation, they support our descriptive analysis of TGC prices. To some extent, they indicate that cross-ownership firms potentially have the ability to differentiate TGC prices from their rivals, and this effect is more salient on the demand side than on the supply side of the TGC market.

5.4.1. Robustness tests

One could think that the relationship between pricing of TGCs and the extent of cross-ownership could be endogenous.[7] We argue that this should not be a big concern because of the following reasons. First, in the data available to us, we do not observe any changes in the ownership during the period under consideration. This could be explained by the fact that for many years the largest power producers and retailers in Sweden have been owned by the government (e.g., "Vattenfall") or Swedish municipalities (e.g., "Skellefteå Kraft", "Umeå Energi", "Göteborg Energi"). New entrants in the TGC market (TGC producers or TGC obliged parties) are rather small firms that function either independently or as subsidiaries within established cross-ownership firms. In other words, the ownership data that we possess does not provide enough evidence to conclude that pricing of TGCs is driving the extent or changes in cross-ownership. Second, the TGC scheme is not the major source of income or expenditure for firms that have been active in the TGC market. In other words, we think that other than TGC-related firm activities should be driving firm ownership changes. Third, in our regression models (see Table 6) we use rather aggregate-level TGC prices (i.e., annual weighted-average TGC prices calculated at the level of the parent firm), which should mitigate endogeneity concerns.

However, despite these explanations, to mitigate this endogeneity concern, we run additional regression models as before but control for the extent of cross-ownership of the parent company in two following ways. First, we add a control variable accounting for RES-E capacity calculated at the level of the parent firm. Second, in another set of regressions, we add a control variable accounting for net cumulative holdings of TGCs aggregated at the level of the parent firm. These two variables should capture changes in the size of parent firms with respect to the TGC market. We find that these two variables are insignificant and do not change our main results, as reported in Table 6, in any significant way.[8] However, despite our considerations and additional regression

[7] We thank the anonymous referee for this comment.
[8] The result from the additional regression models can be obtained from the authors upon request.

Table 6
Regression-based analysis of TGC prices.

	All sales	Sales outside parent company	All purchases	Purchases outside parent company	Trading within parent company
	(1)	(2)	(3)	(4)	(5)
D_2003*CO	18.94***	18.20***	−38.11***	−36.32***	
	(5.340)	(5.391)	(6.663)	(6.590)	
D_2004*CO	11.27**	10.04**	−27.64***	−27.03***	87.55
	(4.987)	(5.038)	(5.840)	(5.775)	(57.15)
D_2005*CO	7.689	6.725	−25.25***	−24.45***	69.42
	(4.832)	(4.876)	(5.594)	(5.513)	(42.98)
D_2006*CO	2.990	1.777	−35.76***	−33.78***	−12.83
	(4.717)	(4.756)	(5.411)	(5.342)	(43.00)
D_2007*CO	17.38***	17.17***	−52.23***	−50.48***	60.52*
	(4.579)	(4.613)	(5.239)	(5.173)	(33.84)
D_2008*CO	21.62***	21.83***	−37.29***	−37.00***	103.8***
	(4.473)	(4.512)	(5.163)	(5.100)	(32.66)
D_2009*CO	16.81***	16.93***	−30.25***	−28.54***	45.22
	(4.370)	(4.406)	(5.137)	(5.075)	(32.78)
D_2010*CO	2.147	0.834	−10.80**	−9.523*	16.55
	(4.311)	(4.335)	(5.070)	(5.008)	(31.22)
D_2012*CO	8.447**	7.547*	−35.03***	−34.67***	49.46
	(4.188)	(4.210)	(5.104)	(5.057)	(31.23)
D_2013*CO	8.107*	6.414	−18.76***	−18.60***	45.29
	(4.555)	(4.580)	(5.191)	(5.122)	(30.79)
D_2014*CO	5.276	4.334	−12.42**	−11.64**	50.47*
	(4.579)	(4.611)	(5.131)	(5.076)	(30.10)
D_2015*CO	4.185	3.477	−17.51***	−17.82***	52.74*
	(4.464)	(4.488)	(5.074)	(5.020)	(30.72)
D_2016*CO	−2.759	−3.145	3.229	2.710	41.49
	(4.337)	(4.368)	(5.054)	(5.008)	(31.28)
D_2017*CO	0.854	0.0655	−19.41***	−20.37***	38.61
	(4.346)	(4.377)	(5.087)	(5.039)	(31.65)
D_2018*CO	8.446*	8.352*	−35.34***	−37.00***	48.60
	(4.315)	(4.349)	(5.084)	(5.031)	(30.80)
Constant	204.7***	204.7***	188.4***	187.8***	206.9***
	(1.288)	(1.289)	(1.765)	(1.739)	(10.63)
No. of obsv.	10 898	10 824	6292	6221	322
R-squared	0.667	0.668	0.735	0.746	0.588
No. of parent firms	1802	1794	1238	1236	57

Notes: Dependent variable is the annual average volume-weighted price of TGCs sold/purchased by parent company. Reference year is 2011. To save space, we do not report the estimated coefficients for the year dummy variables in this table. These results are available from the authors upon request. Standard errors in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

results, we urge future research to investigate further the relationship between TGC prices and ownership.

6. Conclusions and policy implications

The aim of this paper is to investigate the implications of cross-ownership in the TGC market. We postulate that cross-ownership in any TGC market is relevant because the largest obligation to comply with the TGC system typically falls on electricity retailers, many of which are also producers of green electricity, who are eligible to receive TGCs. This is confirmed by our analysis of the Swedish TGC market during the period 2003–2018, where, at the time of implementation of this market, cross-owned firms owned more than 80 percent of firm-owned RES-E capacity and received more than 80 percent of the firm-received TGCs. Over time, this dominance has decreased but still amounted to a significant share of TGCs. In contrast to what is observed on the supply side, cross-ownership on the demand side has increased over time, accounting for almost half of all obliged TGCs.

Furthermore, we find that, even if cross-ownership in the Swedish TGC market was significant, market concentration of the entire TGC market (supply and demand) was low – and it has decreased over time due to more players entering the market. Despite the absence of market concentration, our analysis of TGC prices indicates that cross-ownership firms had the ability to differentiate TGC prices from non-cross-ownership firms, especially, on the demand side of the TGC market. Such behavior is consistent with the behavioral assumption that the ultimate owner's objective is to maximize the total profit of the portfolio of shares, and that, therefore, the pricing behavior would differ from that of a perfectly competitive firm without ownership links to other firms in the industry.

Although our results lack causal interpretation, they highlight the importance of better understanding the extent of cross-ownership in TGC markets and its implications for firm profitability and final consumer prices. This is particularly relevant at a time when cross-ownership is increasing in several industries, due to the popularity of investment funds allowing investors to diversify their holdings and thereby reduce their exposure to individual firm risks. The causal analysis of the effects of market structure on market outcomes such as prices, profits, and investments are thus suggested as an area for further research.

From a policy perspective, the most important question is what implications cross-ownership has for *cost-efficiency* of the TGC system. Cost-efficiency is assessed by the achievement of a pre-determined target at a minimum cost. In principle, a well-functioning competitive TGC system is cost-efficient. However, the presence of market power (irrespective of its cause) could lead to a higher than competitive TGC price, negatively affecting the cost-effectiveness of the system and increasing the financial burden for final electricity consumers. Our analysis provides some evidence that, due to cross-ownership, TGC prices may be higher than they could have been. It is also very likely that higher TGC prices could be transferred to consumers' electricity bills. Our findings support the earlier analytical findings by Bergek and Jacobsson (2010), who conclude that the Swedish TGC system has turned into a "rent-generating machine" and therefore has performed badly in terms of consumer costs.

The major lesson learned for policy is that, before putting any TGC system in place, it is important to identify *ex-ante* major factors that could hinder the cost-efficiency of the system. An independent *ex-post* evaluation of cost-efficiency is equally important at the early stage of a TGC system. This can be achieved only by ensuring that independent researchers have access to reliable and detailed data on market participants and transactions.

CRediT authorship contribution statement

Jessica Coria: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Jūratė Jaraitė:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of competing interest

No conflict of interest statement.

Data availability

The authors do not have permission to share data.

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Appendix

Table A1
Comparing the means and standard deviations of TGC prices of cross-ownership firms and non-cross-ownership firms, 2003–2018

	Cross-ownership firms, outside vs. within	Non-cross-ownership firms, outside vs. within
Prices of sold TGCs	*p value*	*p value*
H_0: mean (outside) - mean (within) = 0	reject H_0	accept H_0
H_a: mean (outside) - mean (within) > 0	0.000	0.841
H_a: mean (outside) - mean (within) < 0	1.000	0.159
H_0: s.d. (outside)/s.d. (within) = 1	reject H_0	reject H_0
H_a: s.d. (outside)/s.d. (within) > 1	1.000	1.000
H_a: s.d. (outside)/s.d. (within) < 1	0.000	0.000
Prices of purchased TGCs	*p value*	*p value*
H_0: mean (outside) - mean (within) = 0	reject H_0	reject H_0
H_a: mean (outside) - mean (within) > 0	0.000	1.000
H_a: mean (outside) - mean (within) < 0	1.000	0.000
H_0: s.d. (outside)/s.d. (within) = 1	reject H_0	reject H_0
H_a: s.d. (outside)/s.d. (within) > 1	0.044	1.000
H_a: s.d. (outside)/s.d. (within) < 1	0.957	0.000

Notes: We use the *t*-test for two samples to compare the difference in the means of two groups by allowing unequal variances in our samples (ttest command in Stata). We perform the F test on the equality of standard deviation by using sdtest command in Stata. The means and the standard deviations of TGC prices as well as the number of observations for each group are reported in Table 5. "CO" denotes cross-ownership firms, and "non-CO" denotes non-cross-ownership firms.

Table A2
Comparing the means and standard deviations of TGC prices *between* cross-ownership firms and non-cross-ownership firms, 2003–2018

	All transactions	Within parent transactions	Outside parent firm transactions
Prices of sold TGCs	*p value*	*p value*	*p value*
H_0: mean (non-CO) - mean (CO) = 0	accept H_0	reject H_0	accept H_0
H_a: mean (non-CO) - mean (CO) > 0	0.165	0.000	0.802
H_a: mean (non-CO) - mean (CO) < 0	0.835	1.000	0.198
H_0: s.d. (non-CO)/s.d. (CO) = 1	reject H_0	reject H_0	reject H_0
H_a: s.d. (non-CO)/s.d. (CO) > 1	0.000	0.000	0.000
H_a: s.d. (non-CO)/s.d. (CO) < 1	1.000	1.000	1.000
Prices of purchased TGCs	*p value*	*p value*	*p value*
H_0: mean (non-CO) - mean (CO) = 0	reject H_0	reject H_0	reject H_0
H_a: mean (non-CO) - mean (CO) > 0	1.000	0.000	1.000
H_a: mean (non-CO) - mean (CO) < 0	0.000	1.000	0.000
H_0: s.d. (non-CO)/s.d. (CO) = 1	reject H_0	reject H_0	reject H_0
H_a: s.d. (non-CO)/s.d. (CO) > 1	1.000	0.000	1.000
H_a: s.d. (non-CO)/s.d. (CO) < 1	0.000	1.000	0.000

Notes: We use the *t*-test for two samples to compare the difference in the means of two groups by allowing unequal variances in our samples (ttest command in Stata). We perform the F test on the equality of standard deviation by using sdtest command in Stata. The means and the standard deviations of TGC prices as well as the number of observations for each group are reported in Table 5. "CO" denotes cross-ownership firms, and "non-CO" denotes non-cross-ownership firms.

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