Essays on Policy and Market Imperfections in Electricity and Auction Markets

Kajsa Ganhammar

Lund
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DOCTORAL DISSERTATION
By due permission of the School of Economics and Management, Lund University, Sweden.
To be defended at Holger Crafoords Ekonomicentrum, EC3:210 on June 3, 2025 at 14:00.

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Organization
LUND UNIVERSITY
Department of Economics
P.O. Box 7082
220 07 LUND
Sweden

Document name
DOCTORAL DISSERTATION

Date of disputation
2025-06-03

Sponsoring organization

Author(s)
Kajsa Ganhammar

Title and subtitle
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Abstract
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The first paper empirically examines the effect of regulatory uncertainty in quota-based green certificate markets, a market-based subsidy scheme for renewable energy. This policy has received criticism for exposing investors to high risk as the subsidy is determined by the market price of certificates. Using data from the Swedish-Norwegian market and a two-step econometric procedure, this paper shows that regulatory interventions in green certificate markets further exacerbate price risk by resulting in periods of higher price volatility, which in turn defers wind power investments.

The second paper theoretically analyses strategic behaviour in the electricity market when incorporating the effect of a coexisting quota-based green certificate market. Using a two-stage duopoly model, I find that when the subsidised technology has a higher expected marginal cost than the conventional technology, the policy can improve competition and efficiency in the electricity market. Conversely, if producers have the same expected marginal cost, the advantage the policy creates enables the subsidised producer to bid higher for a given cost. This is harmful to competition and results in high consumer prices of electricity.

The third paper theoretically analyses search frictions in decentralised markets where sellers post sealed-bid auctions to sell a homogeneous good. The model incorporates search by assuming that buyers can locate only one of two sellers in the market unless they engage in costly search before the auctions start. I find that this leads to price dispersion because only buyers with valuations above a certain threshold are willing to search and attend the less visible auction. A simulation study of the model predictions also shows that search costs lead to ex post welfare losses by reducing aggregate consumer surplus and efficiency.

Key words
Auctions, Electricity markets, Green certificates, Market organisation, Real options, Regulatory uncertainty, Renewable energy, Search frictions, Strategic behaviour

Classification system and/or index terms (if any)
JEL classifications: D22, D43, D44, D47, D81, D83, Q48

Supplementary bibliographical information

Language
English

ISSN and key title
0460-0029 Lund Economics studies no. 246

ISBN
978-91-8104-509-3 (print)
978-91-8104-510-9 (pdf)

Recipient's notes

Number of pages
128

Price

Security classification

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Lund University School of Economics and Management, Department of Economics

ISBN: 978-91-8104-509-3 (print)
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ISSN: 0460-0029 Lund Economics studies no. 246

Printed in Sweden by Media-Tryck, Lund University, Lund 2025

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Acknowledgements

Although the work put into this thesis has at times been frustrating (including numerous unsuccessful attempts at building theoretical models of complex real-world markets), it has also been truly rewarding and fun – in large part because of the many people who helped me along the way. For that, I want to sincerely thank them.

First of all, I would like to express my gratitude to my main supervisor, Tommy Andersson. Thank you for your kindness and patience, the geeky conversations about the fascinating field of market design, and your constant guidance and support, whenever I needed it, throughout these five years. I am so grateful for everything you have taught me and the opportunities that came with being your PhD student. Another special thank you to Pär Holmberg, my assistant supervisor. Your expertise on electricity markets and auction theory has been incredibly valuable to me. Your feedback especially helped improve the second paper in this thesis significantly, and I enjoyed and learned a great deal from our discussions when I visited Stockholm. I also thank the Research Institute of Industrial Economics for the funding and hospitality during these visits, and particularly the rest of the energy group, Thomas Tangerås and Erik Lundin, who invited me to interesting activities on energy economics as well.

I thank Andreas Bergh for valuable guidance during the work on an earlier version of the first paper in this thesis. This and the second paper also greatly benefitted from comments from three anonymous reviewers. In addition, I thank René Kirkegaard for reviewing my third paper and providing great constructive feedback and suggestions. Thanks to generous funding from the Jan Wallanders and Tom Hedelius foundation, I got the opportunity to visit Universidad Carlos III de Madrid in spring 2024. I am grateful to Natalia Fabra for hosting me and for taking the time to provide valuable advice in the early stages of my third paper. To the rest of the EnergyEcoLab team, Clément, Jimmy, and Michael, thank you for interesting discussions on shared research interests during my time at UC3M. Alexandros, Petter, Therese, Petra, Gunes, Erik W, Roel, Andreas E,

Simon, Davide, Pol, Adrian N, and others also provided helpful feedback during seminars and job market training at the department in Lund – thank you.

I have been lucky to be surrounded by many brilliant, supportive, and kind PhD colleagues. Teppo and Negar, thank you for making our cohort such a great one, for all the laughter, and your friendship. I am so impressed by you both. Having you as my office buddy, Negar, also made all the difference during these years. Thank you for listening to all my complaints and for cheering me on, especially during this intense final year. Thanks to Filipe for great company during the first two years of the program, and to Prakriti for the micro theory chats and the good times during the CoED conference in Padua. To my other PhD colleagues over the years: Christina, David S, David W, Devon, Emelie, Hugo, Iker, Ioannis, James, Jonas, Josefin, Linn, Ludvig, Lukas, Madeleine, Marco, Marcus, Matthew, Maxime, Najmeh, Natalie, Ovidijus, Pelle, Qianyan, Ruben, Sandra, Shayan, Steve, Tilman, Wenting, Yunyi, Yuqing – and many more – thank you for all the fun and enriching lunch chats. I also thank the admin team for streamlining our PhD work and for contributing to the positive atmosphere in EC, and Pontus and Karin for valuable teaching advice and for patiently answering all my teaching-related macro-questions.

Finally, a big thank you goes to my family and friends outside the department for their encouragement and for helping me to occasionally take my mind off this thesis. Among them, I especially want to thank my mother, Karolina. I could not have completed this thesis without your immense support. Thanks also to my brother, Axel, for keeping me sane and grounded, and to my brother, Anton, for keeping me motivated by our shared geeky enthusiasms (particularly for running). Last but certainly not least, Totte, thank you for all your patience and support over these past couple of stressful years and for making sure I did not survive on chickpeas and quinoa alone.

Lund, April 2025
Kajsa

Introduction

Introduction

This thesis consists of three self-contained papers. A common theme among them is that they are all somehow connected to electricity markets and particularly green electricity certificates, either explicitly or implicitly. Green certificates are electronic documents used in a growing number of countries to track the origin of electricity and promote renewable energy.[1] These are issued to producers of renewably sourced electricity in proportion to their generation and can be sold in a market separate from the physical market for electricity, providing additional revenue on top of the wholesale electricity price. As such, green certificates make it possible to put a value on the 'greenness' of electricity from renewable sources, since it is impossible to distinguish the origin of electricity once it is fed into the public grid. For example, member states of the European Union are required to use green certificates – called guarantees of origin (GOs) – when making claims about the use of renewable energy (European Parliament, 2018). By purchasing GOs, retailers can thus offer green electricity contracts to consumers, and businesses can make green energy claims to reduce their carbon footprint.

Some countries also have politically enforced quota obligations in place, where electricity providers are obliged to procure a certain amount of green certificates in proportion to their total sales. This is often promoted as a cost-effective policy to stimulate investments in renewable energy technologies to meet climate targets, as it leaves it to the market to determine the support level in terms of the price of certificates. However, the first two papers identify circumstances that can reduce the cost effectiveness of this policy and lead to higher energy costs for consumers. The first paper empirically analyses the effect of regulatory uncertainty in quota-based green certificate markets, using data on certificate prices and wind power investments in the Swedish-Norwegian market.

[1] These certificates are sometimes also referred to as energy attribute certificates, renewable energy certificates, guarantees of origin, among other names.

The second paper theoretically examines how the policy affects competition in the electricity market, noting that producers should rationally incorporate the revenues from green certificates when forming their pricing strategies in the electricity market. In a perfectly competitive market, certificates should therefore put downward pressure on electricity prices as they reduce the net marginal cost of producing green electricity. However, as I show in this paper, this effect may be mitigated if there are dominant producers that strategically bid above their marginal cost.

The second and third papers are related in that they both rely on theoretical analysis using auction models, but they differ in the underlying assumptions regarding the organisation of the markets under consideration. The second paper considers a *centralised* market where producers submit bids through a central exchange, which corresponds to the organisation of most wholesale electricity markets. Other markets, such as those for green certificates in the EU and the US, are *decentralised*. The third paper focuses on a friction common in decentralised markets: the often time-consuming search buyers and sellers have to undertake to locate each other as there is no central exchange to turn to. Unlike the first two papers, this paper does not explicitly focus on electricity markets. Rather, it aims to provide some first insight into the effects of search frictions in competing sealed-bid auctions for homogeneous goods within a simple framework. Nevertheless, the findings of the paper could have implications for green certificate markets, especially the European market for GOs where high search costs have been reported.

Overall, this thesis contributes to our understanding of the functioning of electricity markets, including those for green certificates, and auction markets in the presence of real-world imperfections such as policy instability, asymmetric information, market power, and costly search. I hope that this research can help inform the policy, regulation, and design of such markets. In the remainder of this introduction, I briefly summarise the motivation, main results, and contributions of each paper separately.

Summary of the thesis

Paper I: The effect of regulatory uncertainty in green certificate markets: Evidence from the Swedish-Norwegian market

Market-based climate policies are often promoted as cost-effective and for being aligned with the principles of liberalised electricity markets. Meanwhile, quota-based green certificate schemes have received criticism for exposing investors to

high risk as they face volatile market prices of both electricity and certificates. In this paper, I show that price risk can also be amplified by policy instability, such as frequent or unpredictable changes in the regulatory framework governing the certificate market, based on a case study of the Swedish-Norwegian market.

In particular, by endogenously testing for structural breaks in the variance of certificate prices, I identify several regimes of increased volatility that can be traced to regulatory interventions. Two of them relate to the expansion of the Swedish market to include Norway in 2012, where the market went through a temporary regime of higher volatility during the negotiations leading up to the introduction of the joint market, as well as in the period following the start of the joint mechanism. A third relates to the uncertain political environment in 2016, which created ambiguity about when the inclusion of new plants in the scheme should be stopped and thus about the termination of the market.

Increased volatility exacerbates the uncertainty about expected revenues from the support policy. The study therefore proceeds to conduct a survival analysis to investigate how investors respond to price uncertainty, using registry data on Swedish onshore wind power investments. I find that a one standard deviation increase in certificate price volatility reduces the probability of project development by 12%, indicating that investors delay investments when uncertainty is high. This can reduce the cost effectiveness of the policy, as wind power is a low-cost renewable technology and new production may not arrive in time to meet an increasing demand when investment decisions are delayed, pushing certificate prices upward. This could in turn trigger an overinvestment, resulting in periods of very low prices, further reducing investor confidence. I am not able to say whether it is regulatory interventions specifically that defer investments, but the connection between high-volatility regimes and political deliberations identified in the first part of the study points in this direction. Regardless, regulators should aim to diminish policy instability that results in price volatility to avoid disrupting the investment climate.

The findings of this study demonstrate the value of transparency and the provision of clear information in political deliberations to create cost-effective market-based support schemes for renewable energy. The paper extends the work of Fagiani and Hakvoort (2014), the first paper to investigate the link between policy instability and price volatility in green certificate markets, by directly investigating the effect of uncertainty on investments. In doing so, it adds to the small existing empirical literature on investment behaviour under uncertainty in green certificate markets, as well as to the larger literature on the evaluation of support schemes for renewable energy.

Paper II: Bidding behaviour in interdependent markets for electricity and green certificates

Understanding how subsidies for renewable energy affect producers' pricing incentives in the electricity market is key in evaluating the costs and benefits of such policies. The second paper addresses this question, focusing on quota-based green certificate schemes. I develop a stylised two-stage duopoly model in which producers first compete to serve electricity demand in a setup similar to that in von der Fehr and Harbord (1993), the first paper to adopt an auction approach to model electricity markets. However, I assume that one producer is green and receives revenues on top of the wholesale electricity price from selling green certificates. Thus, the relevant cost measure that this producer should place its bids in the electricity market upon is the net marginal cost after subtracting the certificate price. Certificates are traded bilaterally in the second stage of the model between the green producer and a retailer that is obligated to purchase certificates.

The findings of the paper indicate that regulators should be concerned about dominant producers entitled to certificates, especially when they compete against technologies with a similar cost range. This could be the case in markets that already have a considerable share of non-subsidised mature renewables with low variable costs, like in hydro-dominated markets, or if the cost of biofuels should fall to a similar range as fossil fuels, or vice versa.

Specifically, focusing on producers that are large enough to satisfy the entire electricity demand, I find that, when they have the same expected marginal cost, the advantage the certificate policy creates enables the subsidised producer to bid higher for a given cost. I estimate numerically that 57% of the cost reduction caused by the revenues from certificates is reflected in the bids of this producer, while the remainder is added markup. This is bad news for consumers, since the consumer price of electricity is based on the sum of the wholesale electricity and certificate prices. Meanwhile, I identify circumstances where this effect is mitigated when the subsidised technology has a higher expected marginal cost than the conventional technology. In particular, the results suggest that careful specification of the penalty for non-compliance – which implicitly caps the certificate price – as well as the lower price bound on certificates (if it exists) is important to avoid considerable markups and unnecessary harm to competition and efficiency when there are strategic producers of green electricity.

Previous theoretical research on the effect of green certificate schemes on electricity market outcomes is predominately based on assumptions of perfect competition. Some studies account for the possibility of strategic behaviour, a realistic

feature of electricity markets, but assume Cournot-like competition and complete information. The main contribution of this paper is therefore that it relies on an auction model, which more closely resembles the organisation of electricity markets, and relaxes the assumption of commonly known generation costs. Meanwhile, this comes at the cost of some other simplifying assumptions, and more research is needed to fully address the welfare effects.

Paper III: Search frictions in competing sealed-bid auction markets

In modern markets, trade can be organised in a variety of different ways. This makes it an important concern to understand the search behaviour of consumers, and any frictions encountered in this process, not only in markets where sellers post fixed prices but also more sophisticated mechanisms like auctions. Indeed, the use of auctions in decentralised markets is becoming increasingly commonplace as more trade moves online (Vulkan and Neeman, 2013; Malamud and Rostek, 2017). Motivated by this, the third paper develops a stylised model in which two sellers post uniform-price auctions to sell a homogeneous good. It incorporates search by assuming that buyers are aware of the location of only one of the sellers. Before the auctions start, they may engage in costly search to locate the other seller and thereby have a choice of which of the two auctions to bid in.

I identify negative effects on market outcomes and welfare because only buyers with valuations above a certain threshold may engage in costly search. In particular, due to the inability to coordinate participation between auctions, the only equilibrium of the model involves these buyers randomising between attending the 'high-visibility' auction and incurring the search cost to locate and attend the 'low-visibility' auction. This can result in a low degree of efficiency, especially when the search cost is high, as buyers with high valuations of the good may end up going to the same seller. Furthermore, to sustain this equilibrium, the expected price in the low-visibility auction must be lower than in the high-visibility auction to compensate for the search cost. Such price dispersion not only generates winners and losers, but can make it difficult for market participants to estimate the value of the good due to conflicting price signals.

Modelling the decentralised market as competing auctions also allows for a direct comparison of market outcomes in a centralised exchange, by simply merging the single-unit auctions in the model into one multi-unit auction. A similar comparison would be less robust in a model that considers decentralised trade

as a series of bilateral negotiations because it would be difficult to distinguish the effect of centralisation from the effect of simply changing the rules of trade. When it is optimal for buyers to bid their true valuation of the good, like in this model, centralisation not only eliminates search costs but also ensures an efficient allocation of the goods. A simulation study based on the model predictions also shows that the aggregate consumer surplus is larger in the centralised exchange, compared to the decentralised market, when there is a small number of buyers or the search cost is sufficiently high. Likewise, the simulations suggest that measures to reduce search costs in decentralised markets may be particularly effective in relatively small markets, as the effects of search (and coordination) frictions on key welfare measures appear to stagnate as the number of buyers in the market increases. These findings could have relevant implications for the European GO market, where significant search costs have been reported (especially for technology-specific GOs where the market remains small), and there have been calls for more centralised trade (Hulshof et al., 2019; EPEX Spot, 2024; Oslo Economics, 2017; Nord Pool, Granular Energy and AFRY, 2023).

This paper adds to the literature on competing auctions by incorporating search costs. In doing so, it contributes to our understanding of the effects of search frictions in decentralised markets. To my knowledge, there exist only a few studies that explicitly incorporate search costs into dynamic auction models. Meanwhile, in this paper, I consider static, sealed-bid auctions where buyers cannot use information revealed during the auction process to potentially coordinate how and where to bid. This type of auction format is commonly used to trade electricity, green certificates, and many financial instruments.

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Printed by Media-Tryck, Lund 2025 NORDIC SWAN ECOLABEL 3041 0903

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SCHOOL OF ECONOMICS AND MANAGEMENT

Lund University
Department of Economics
ISBN: 978-91-8104-509-3
ISSN: 0460-0029